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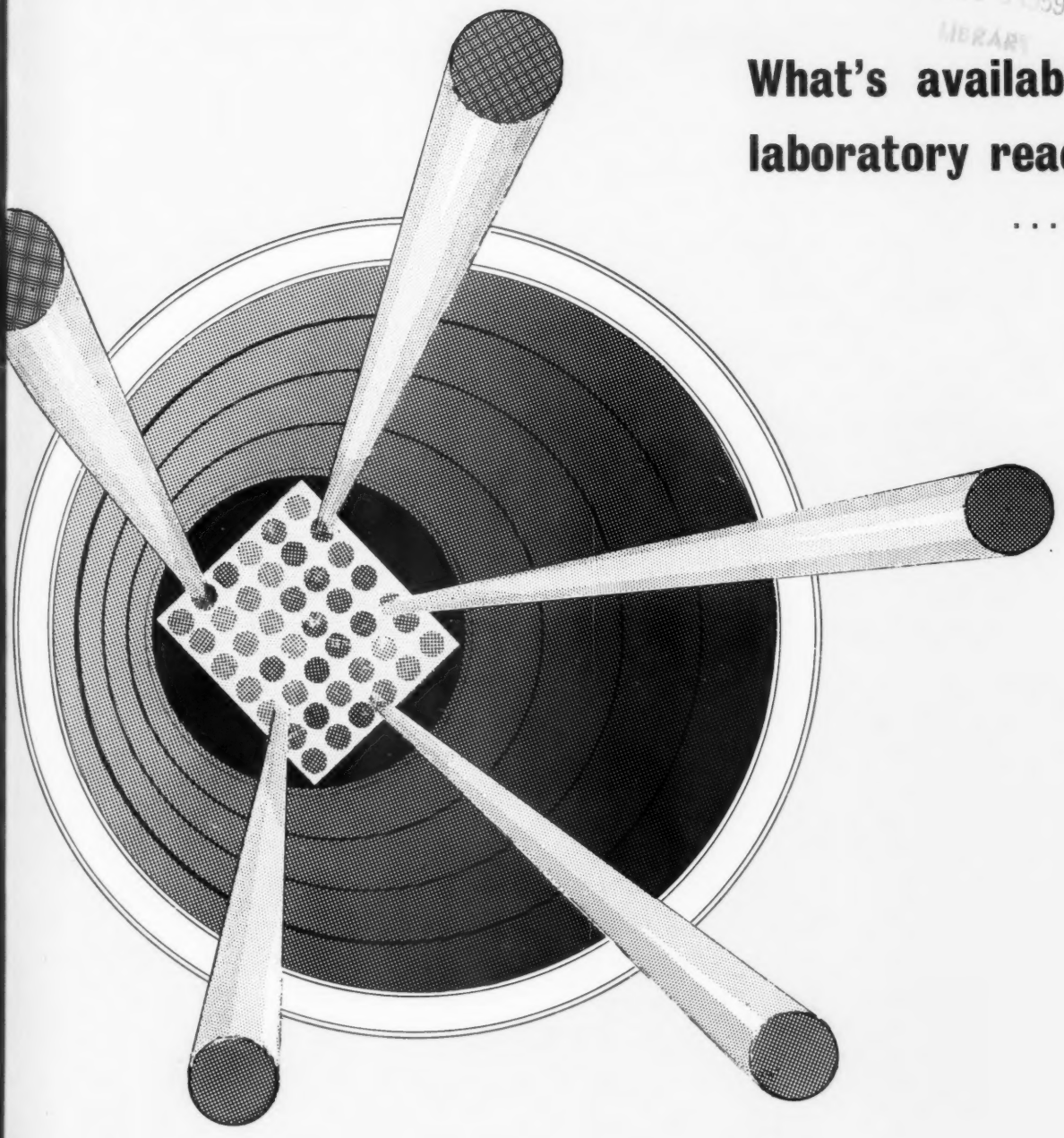

What's available in laboratory reactors

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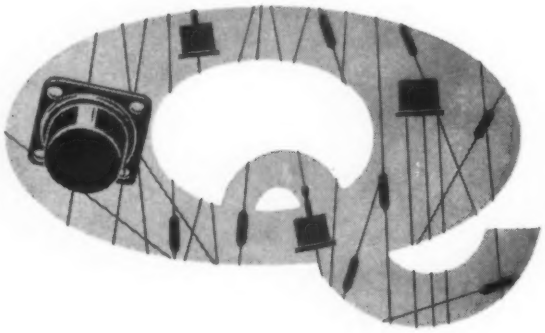

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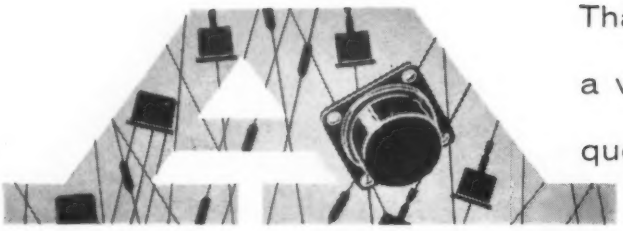

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VOL 4 NO 35 MARCH 1959

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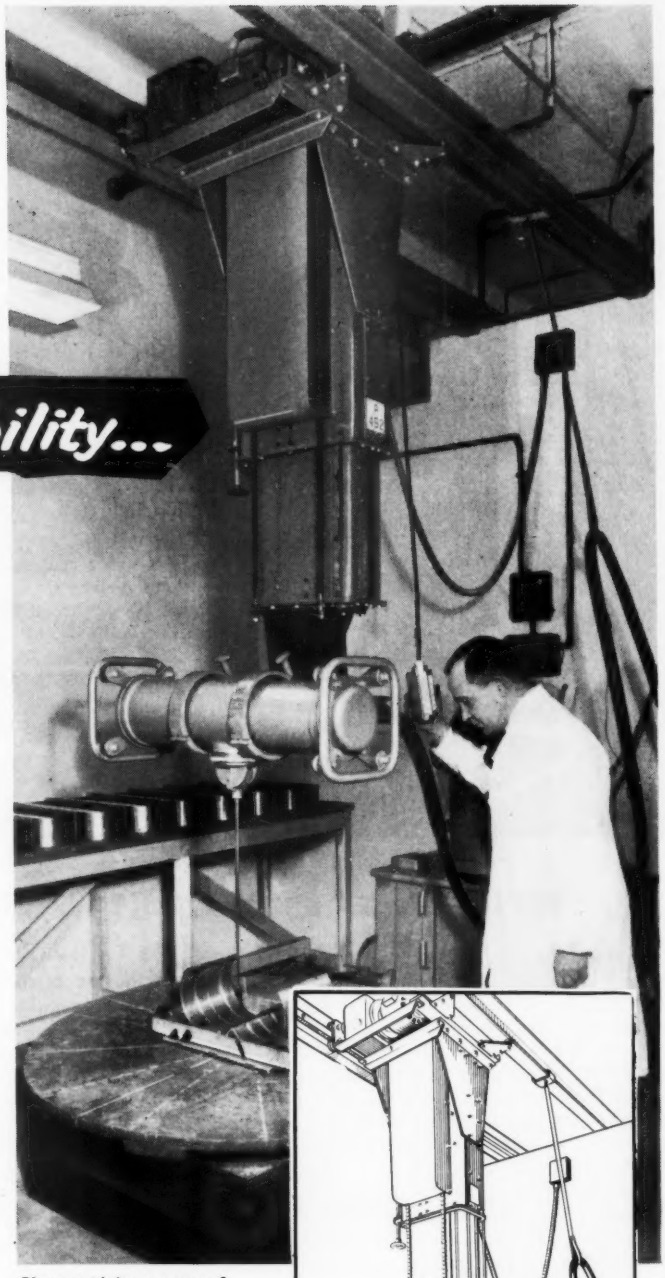

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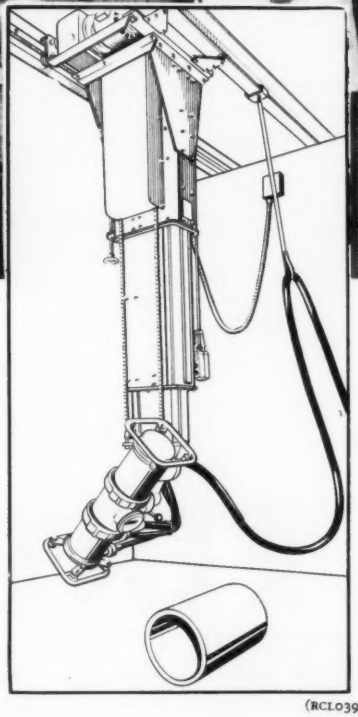

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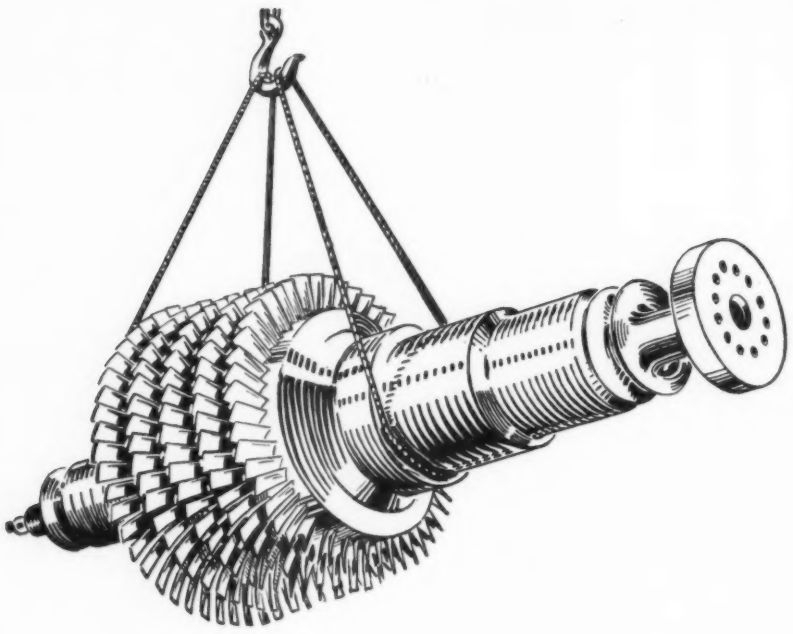

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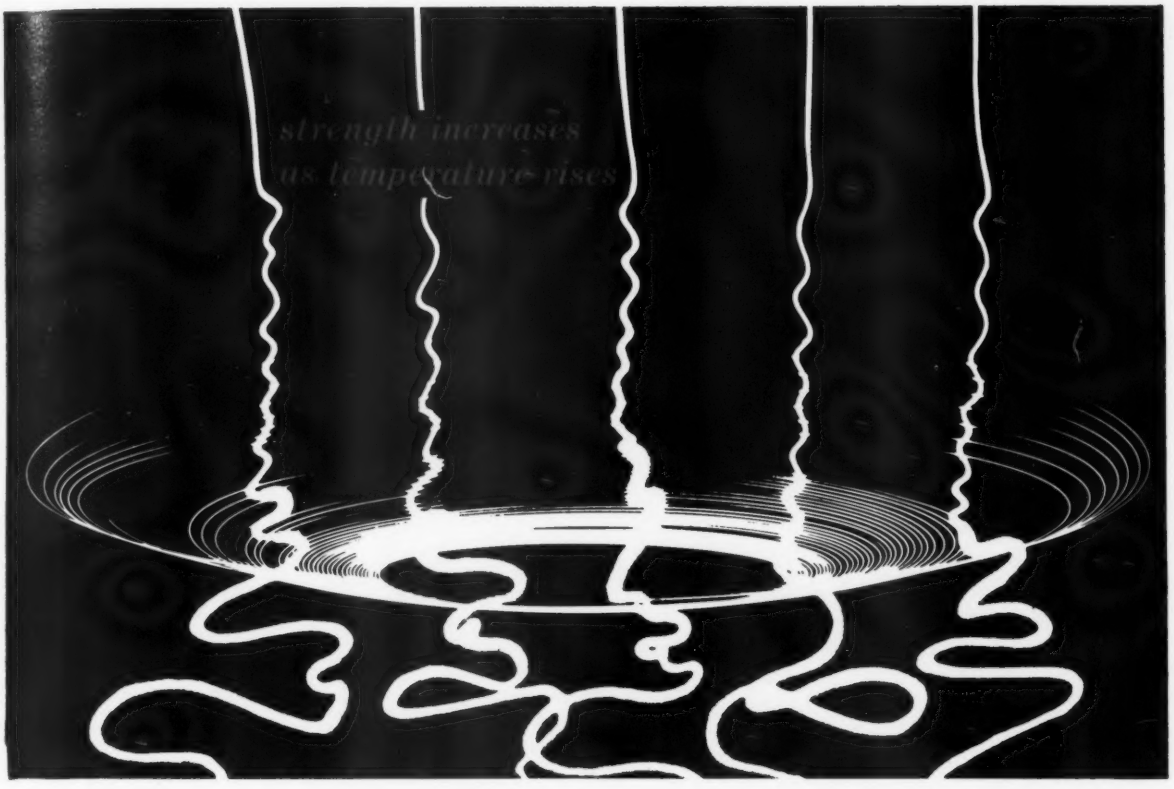

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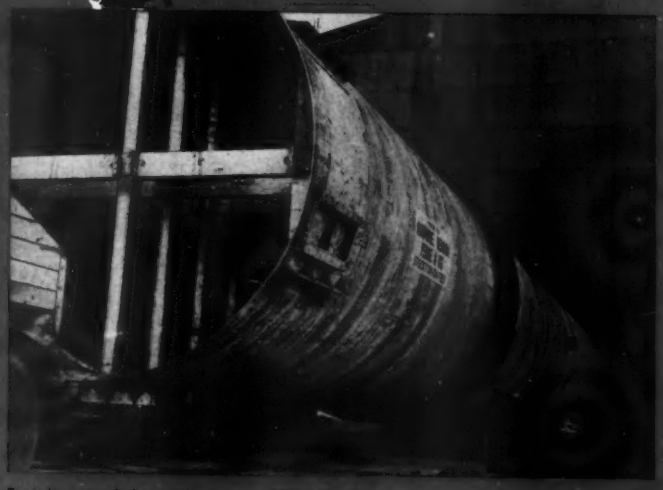

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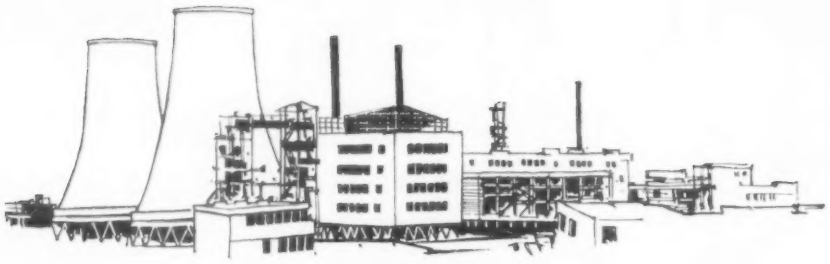

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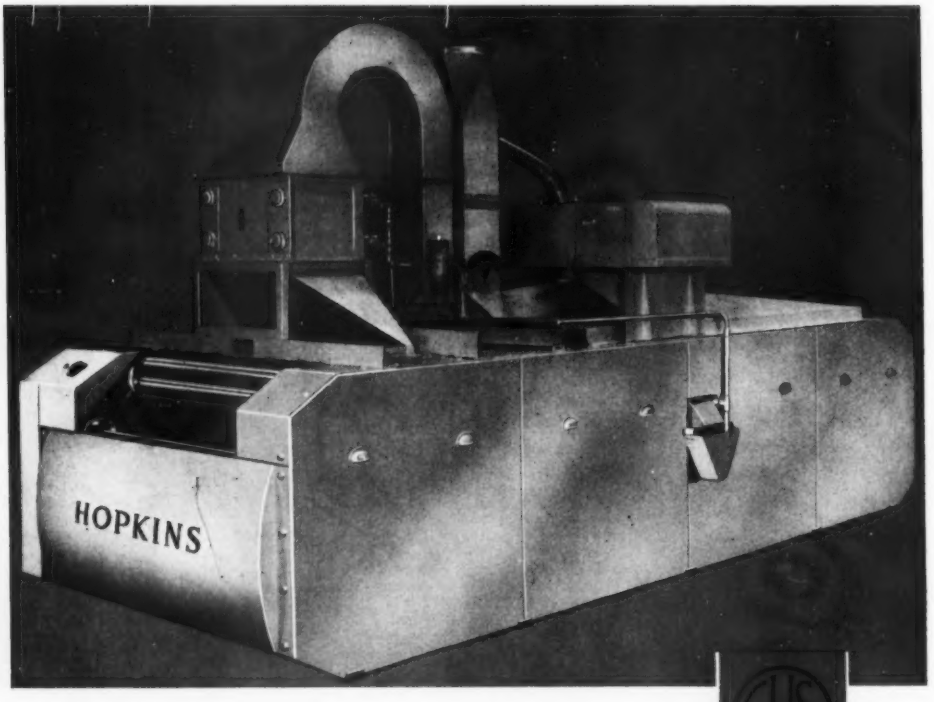

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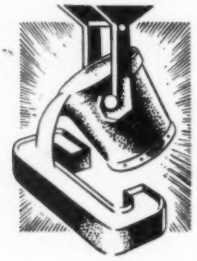

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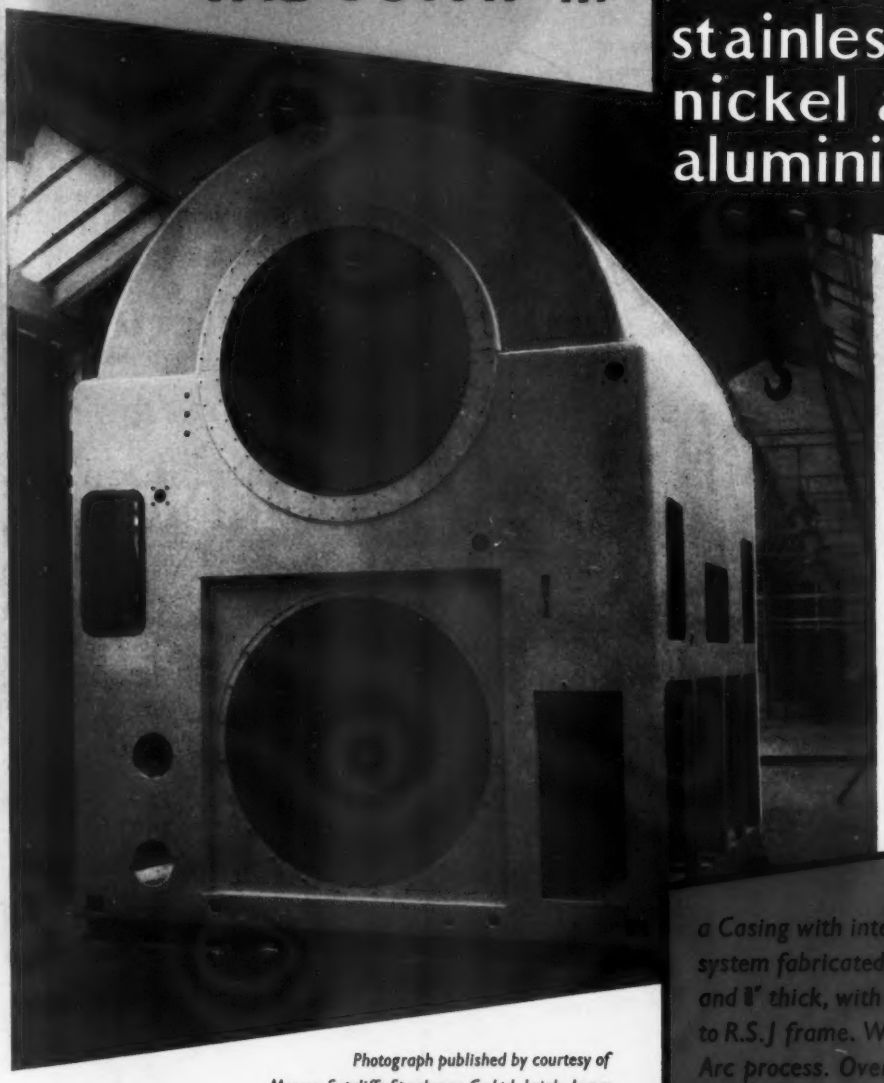

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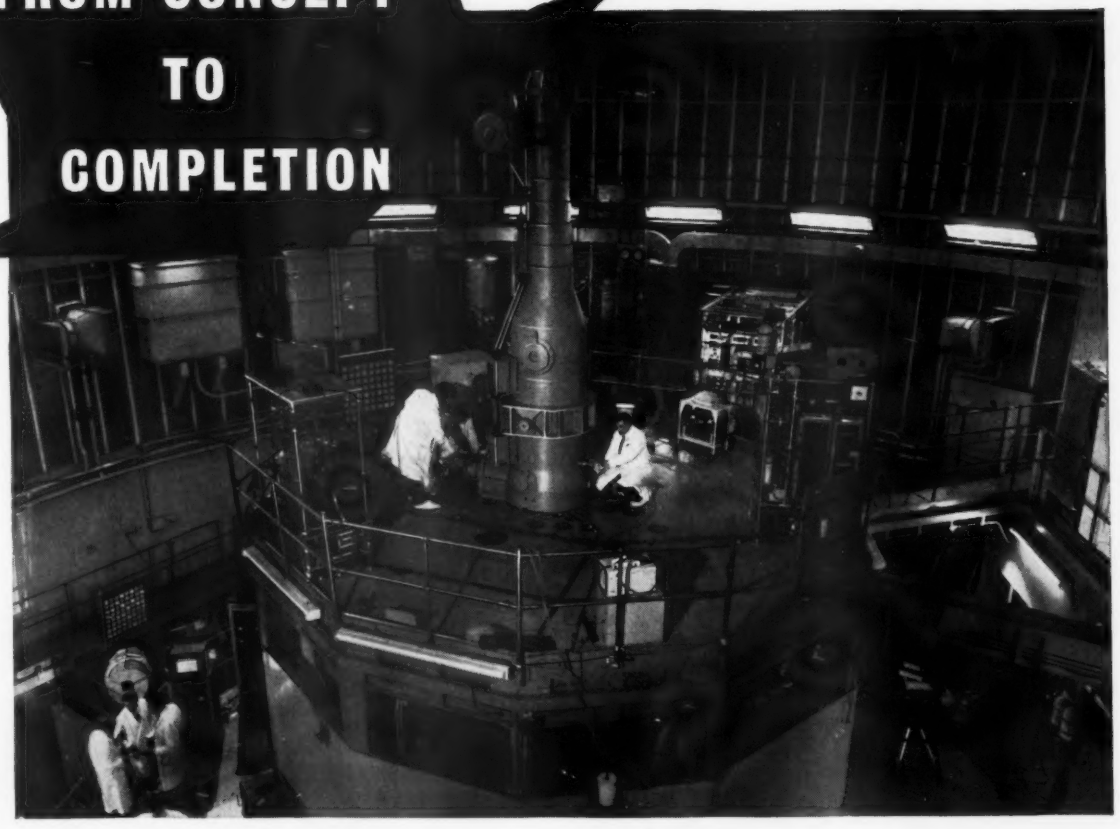

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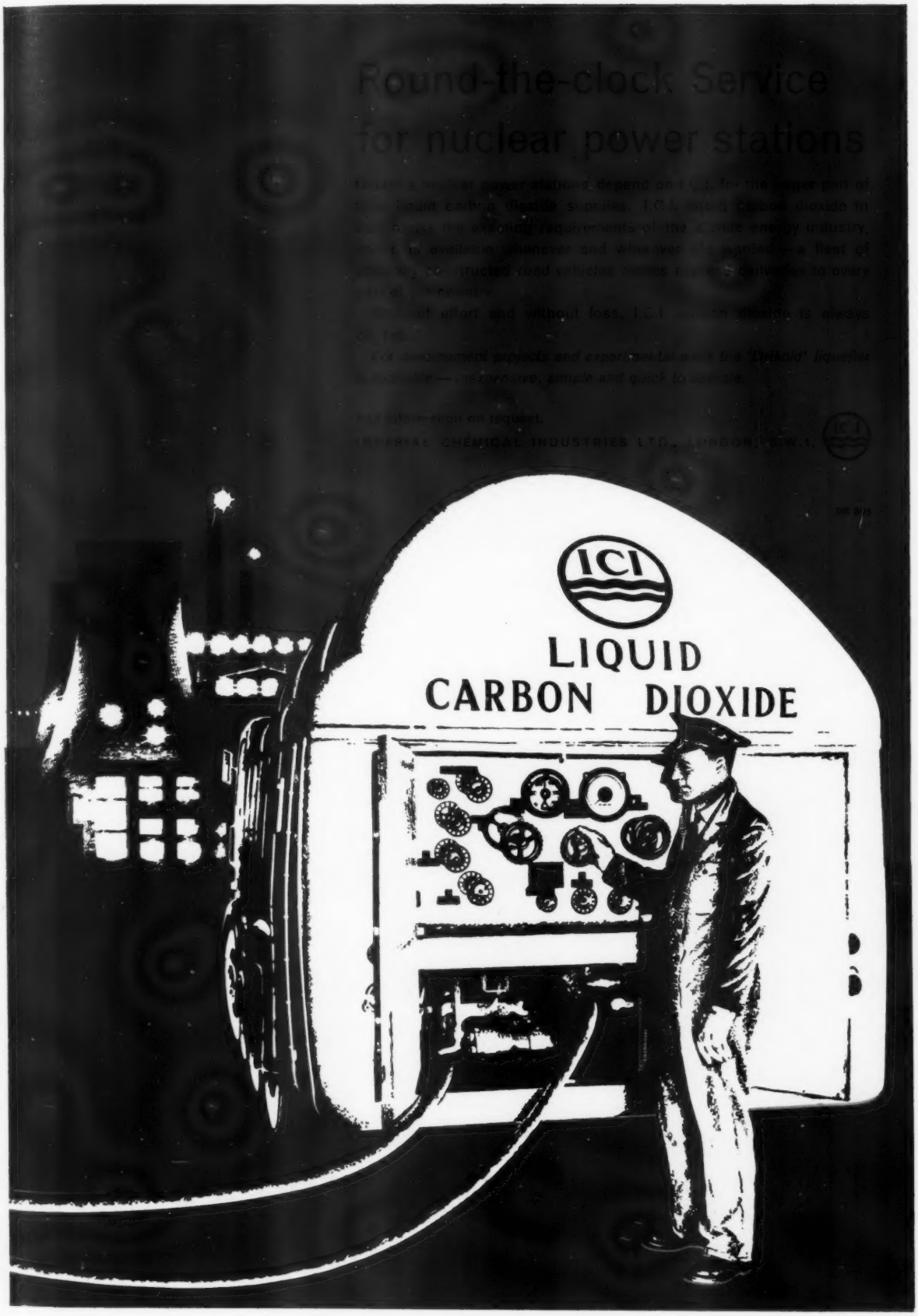

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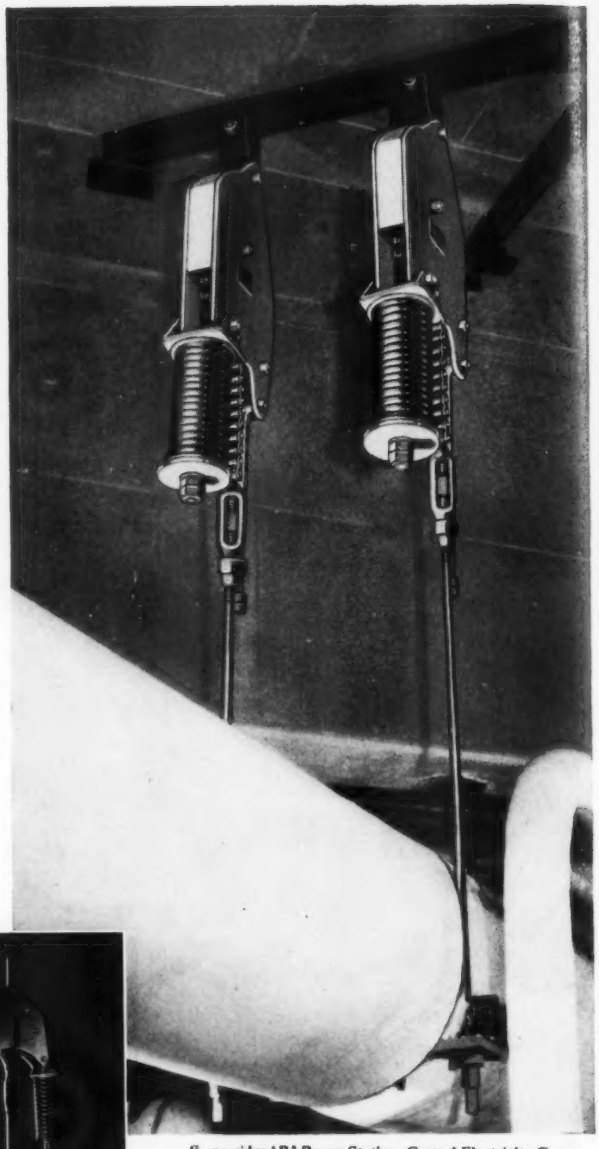
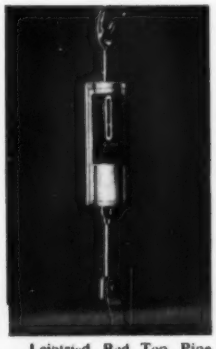


Ferrybridge 'B' Power Station, Central Electricity Generating Board, Yorkshire Division. H.P. Steam pipes supplied and installed by Stewarts and Lloyds Ltd.



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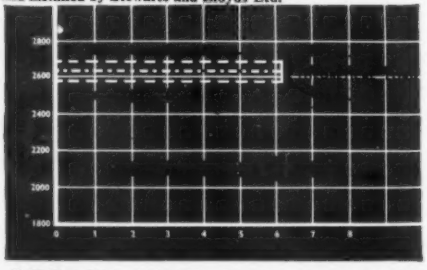

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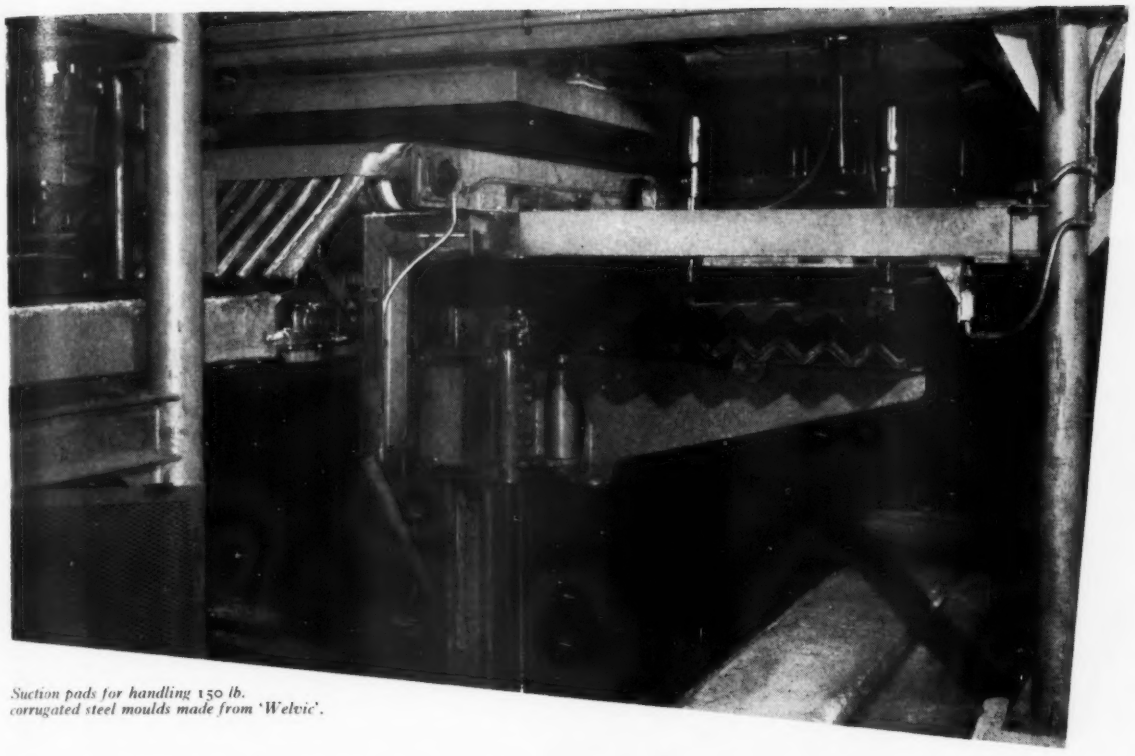

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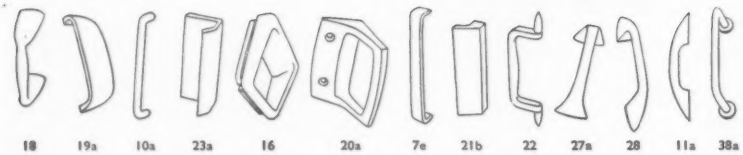

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One of two banks of Vokes 'Absolute' filters in the G.E.C. beryllium laboratory, showing operator in a pressure suit changing a filter.

Vokes Filters specified for work on Beryllium

New Beryllium Laboratory

At the G.E.C. Atomic Energy Division at Erith a new laboratory has been specially designed for work on beryllium. Vokes were called in to assist in the planning of a ventilating system designed to maintain a very high standard of safety and to conform with the recommendations of the U.K.A.E.A.

A Vokes filter can be seen on the left of the lathe enclosed in the PERSPEX working box.

Vokes 'Absolute' Filters

The laboratory areas are fully air-conditioned by means of a central inlet air duct and there is a range of extract ducting running along the laboratory walls.

The extraction system consists basically of a fan drawing air at the rate of 8,000 cub. ft. per min. from the laboratory through 12 Vokes 'Absolute' filters arranged in two banks of six, coupled in parallel to the extract fan. Each of these filters is individually mounted in a cell on the manifold to minimise hazards during filter changing.

The Vokes 'Absolute' filter has a guaranteed efficiency of 99.95% in the 0.1 to 0.5 micron range. For particles greater than 1 micron the efficiency is virtually 100%. The plant has been arranged so that the filters can be changed with the ventilation plant running.

Working Boxes fitted with Vokes Filters

Operations involving the formation of beryllium dust, such as machining, abrasion and welding, are confined to a laboratory where the highest ventilation rate is available and is carried on in ventilated working boxes, which also incorporate Vokes filters.

Where filtration to a particularly high standard is required, as in this case at Erith, Vokes filtration experts are available from planning stage to final installation. If you have a filtration problem, please contact us.

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V.315

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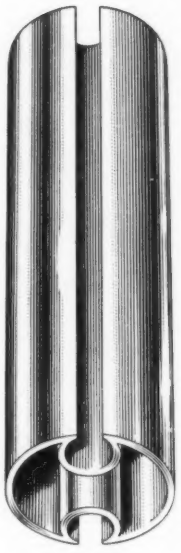
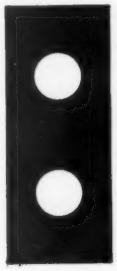
Some recent developments in manufacturing techniques and special applications of tubes in a variety of metals . . .

No. 1 OF A SERIES BY ACCLES & POLLOCK

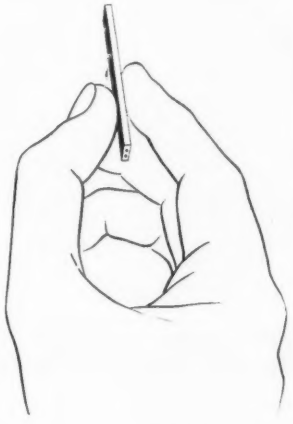


A special section used in sliding door mechanism, the dimensions are: 1″ diameter to take 5/16″ rollers.

Helically convoluted seamless stainless tubing, available in a range of sizes. Can be supplied convoluted in continuous lengths, or with plain ends, or with plain portions at any intermediate point along the tube.



A rectangular tube in pure nickel: .111″ x .045″ A/F with twin bores of .020″ diameter; used in the electrical industry.



Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

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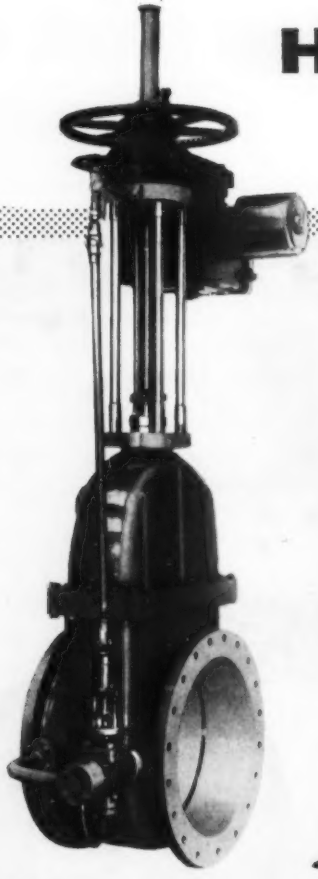

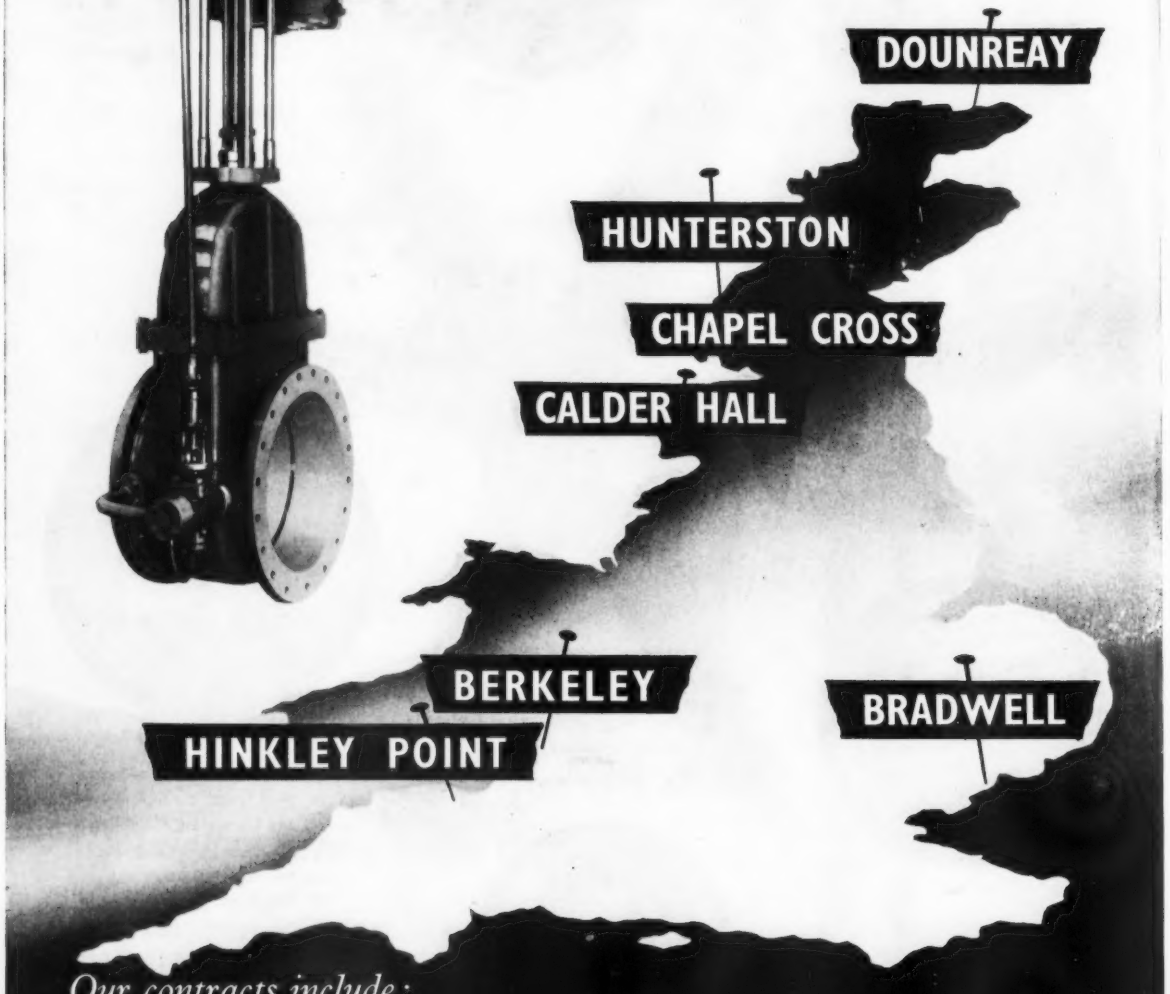

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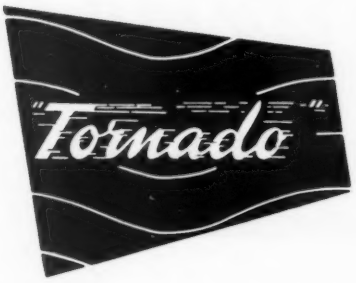

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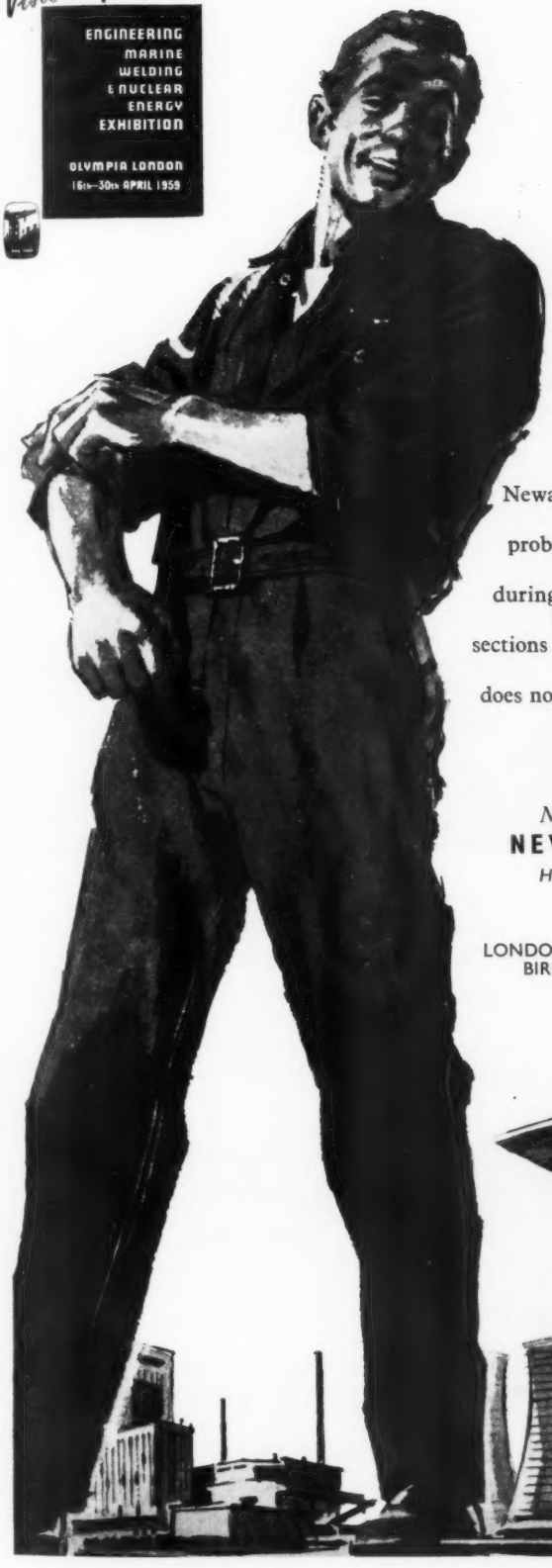

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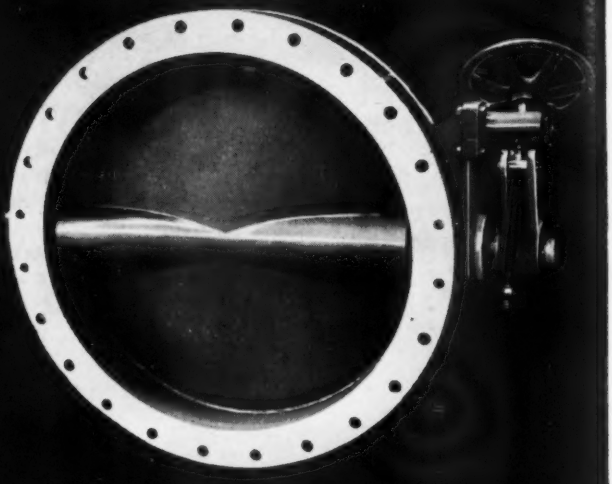
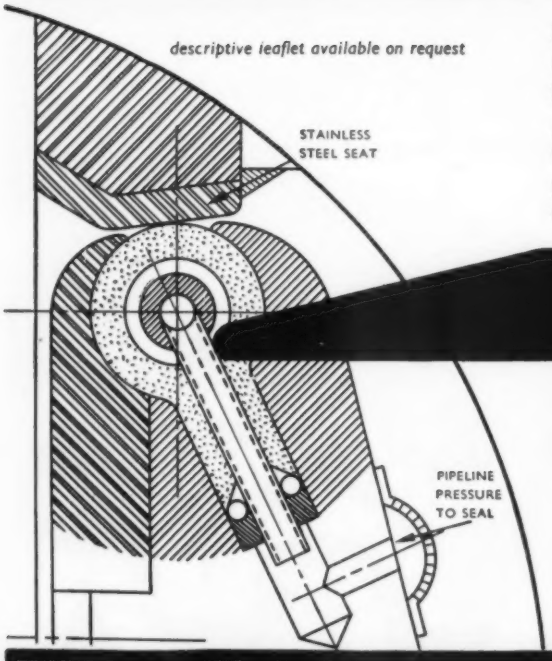


descriptive leaflet available on request



Low Pressure Butterfly Valves suitable for gases and fluids—including sea water. Vertical or horizontal mounting. Hand or power operated. Range 36 to 120 inches. Larger sizes to order.

Around the periphery of the valve blade is the expanding seal. With the valve closed the inside of the seal is subject to pipe-line pressure. This pressure balances external pressure and prevents seal from collapsing away from the seating.

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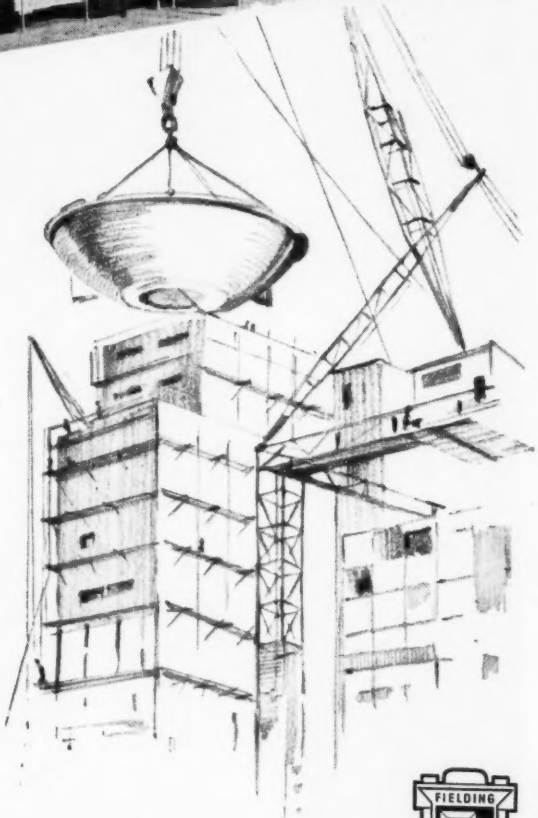

Helping to solve another Pressing problem

The "FIELDING" 4,500 Tons, upstroking multi-ram plate press designed for the Whessoe Company Limited, Darlington, is assisting Britain's race in the field of nuclear power. Shaping the heavy steel plates, required for the shell of giant reactor pressure vessels is only one of the applications to which this press can be applied. It will accept the largest plates manufactured by the British Steel Industry today and still has a substantial margin of power to meet future developments.

This press is only one of the large range of special and standard equipment manufactured by Fielding's; if you have a pressing problem your solution may lie with us. Our Technical Departments are always available to provide information and assistance.

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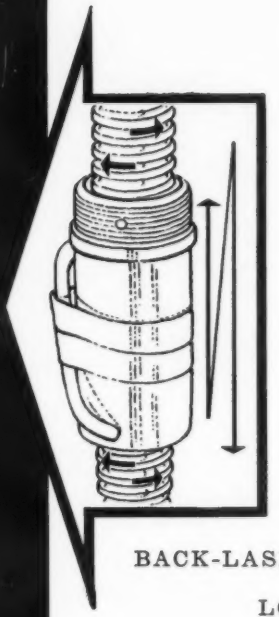

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MXR 506

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"Muraflux A" is the first of a new range of Murex granular fluxes for submerged-arc welding. It has been specially developed for the welding of mild steel by all machines using A.C. or D.C. for submerged-arc welding.

The flux may be used with ordinary filler wires but is specially recommended for use with "Murawire W1" or "Murawire W2" supplied by Murex. When used with these wires, "Muraflux A" produces welds of high radiographic standard suitable for Class 1 work, and the flux has been granted approval by Lloyd's Register of Shipping and is accepted by the Ministry of Transport.

"Muraflux A" is suitable for either the single pass or multi-pass welding of various joints in mild steel as well as plug welds and the building up of worn mild steel parts. Good penetration can be obtained and unfused flux can be re-covered for further use.

"Muraflux S.1" granular flux for the submerged-arc welding of stainless steel is also available with the appropriate Murex S.W.1 and S.W.2 filler wires.

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G.E.C.

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Heavy Alloy

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For Gamma Absorption

An orbital teletherapy unit using G.E.C. Heavy Alloy.
With acknowledgements to Atomic Energy of Canada Ltd.

A 6" G.E.C. Heavy Alloy Sphere weighing 65 lbs. being placed in an 8" lead wall in the Isotope Division, Harwell.

Informative publication No. 3861 on application.

G.E.C.

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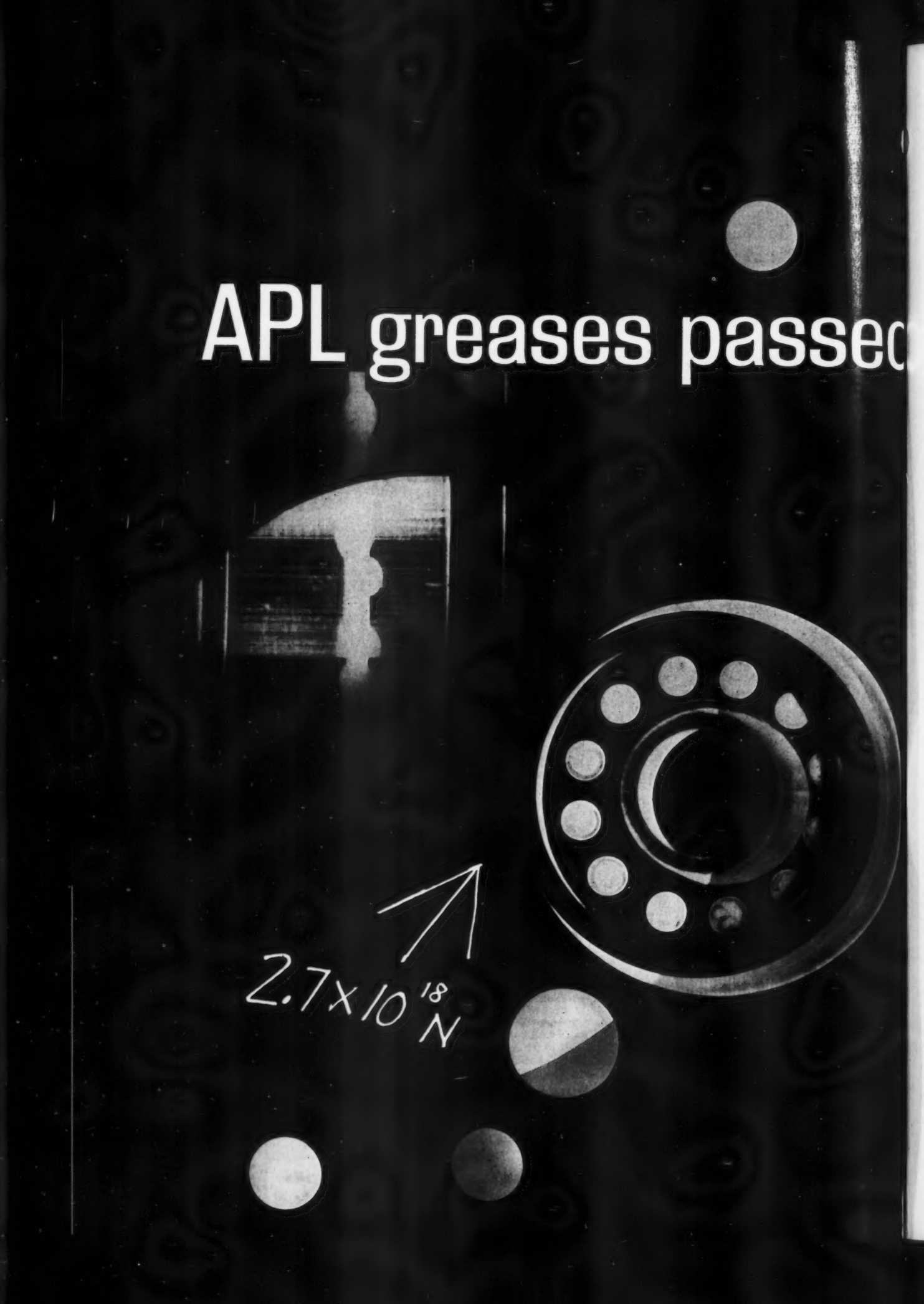
APL greases passed



the final test...

Radiation broke up the gel structure of conventional greases. They lost their lubricating properties, turned fluid or granulated. Completely new kinds of greases were needed by the atomic power industry for the bearings situated within the radiation field.

The Shell Group started working out radiation-resistant APL greases whilst most nuclear power stations were still on the drawing-board, and the research that went into them is characteristic of the way Shell set about doing things.

A team of research workers was assembled at Shell's Research Centre at Thornton. After four years of research and testing – both at Thornton and the A.E.R.E. Harwell – APL greases were ready for their finals. A sample was packed into a bearing and sunk into the B.E.P.O. pile. There it was not only subjected to mechanical working and high temperatures in CO_2, but also to an integrated pile dosage of 2.7×10^{18} thermal N. per sq. cm. plus associated radiation. APL greases sailed through their finals – and Shell are proud of it. They should be. For with these greases, Shell completed Britain's first range of Atomic Power Lubricants.

The moral of the APL story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right lubricant for the job. If you and your organisation have any major lubrication problem, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

Naturally a whole variety of greases were investigated. Conventional metallic soap greases were affected even by relatively low levels of radiation. Other greases based on synthetic and non-petroleum materials were examined and found to be equally unstable. Some of them softened appreciably and became tacky, whilst others hardened.

The Shell APL 700 series of greases are specially processed with an inorganic gelling agent, the base lubricant used being similar to the APL oils previously proved highly resistant to radiation. There were three series of tests. First tests were preliminary radiation tests at Harwell. Then the greases were tested for their lubricating qualities in a high temperature (400°F) pressurised CO_2 anti-friction bearing rig turning at 1,500 r.p.m. For the final tests, actual working conditions were simulated at Harwell.

SHELL

ATOMIC POWER LUBRICANTS

another proof of Shell leadership in lubrication

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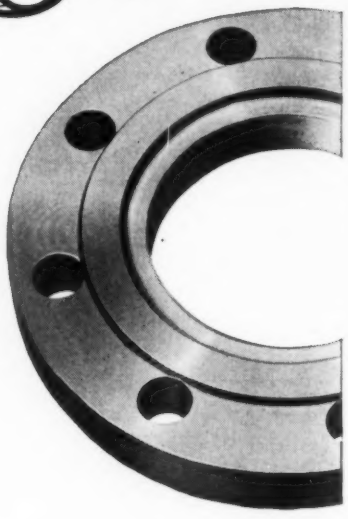
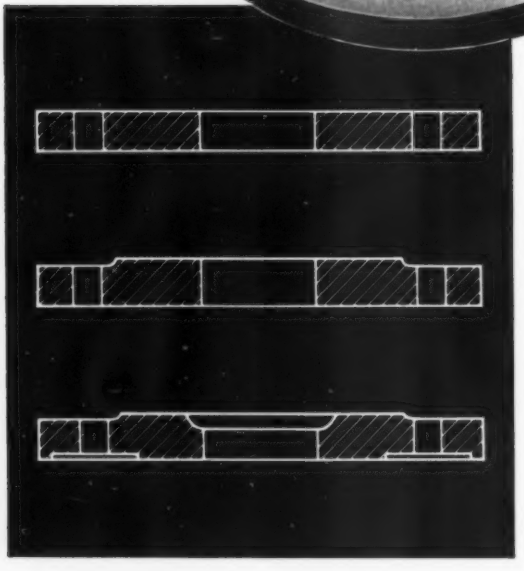
MILD STEEL PLATE TYPE

flanges





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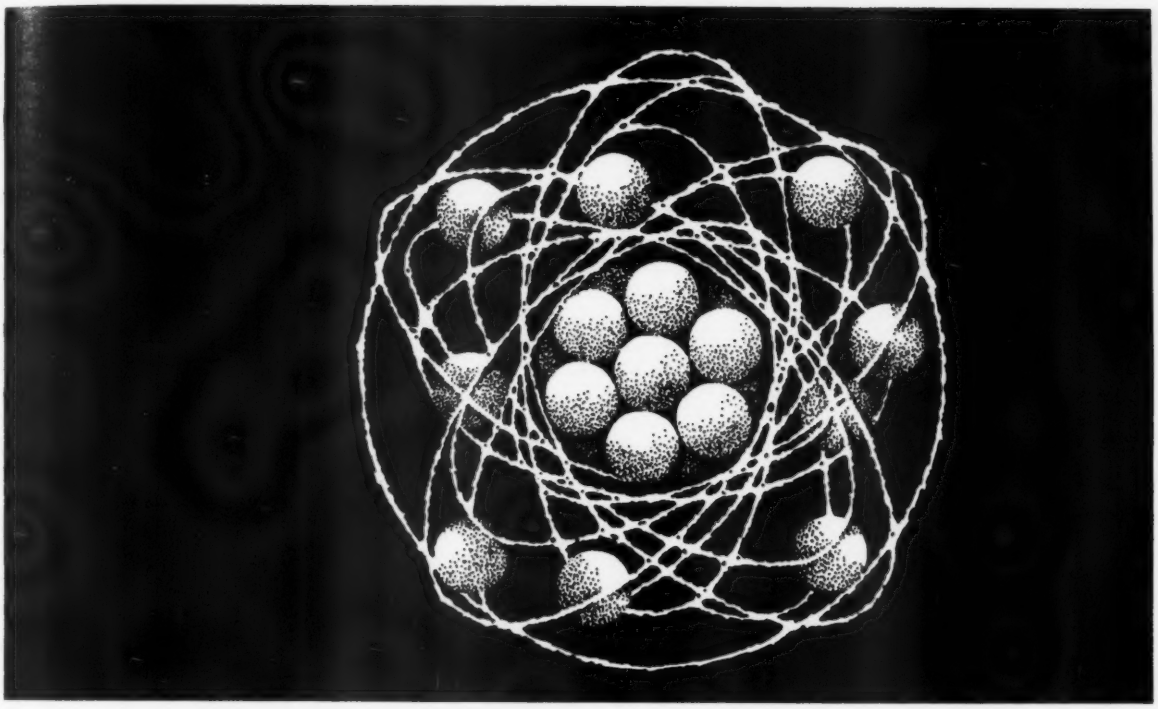

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External means are used in order to urge the disc sealing ring on to or away from the valve seat for closing or opening the valve. Operation can be effected according to requirements by hand, electric, pneumatic and hydraulic means.

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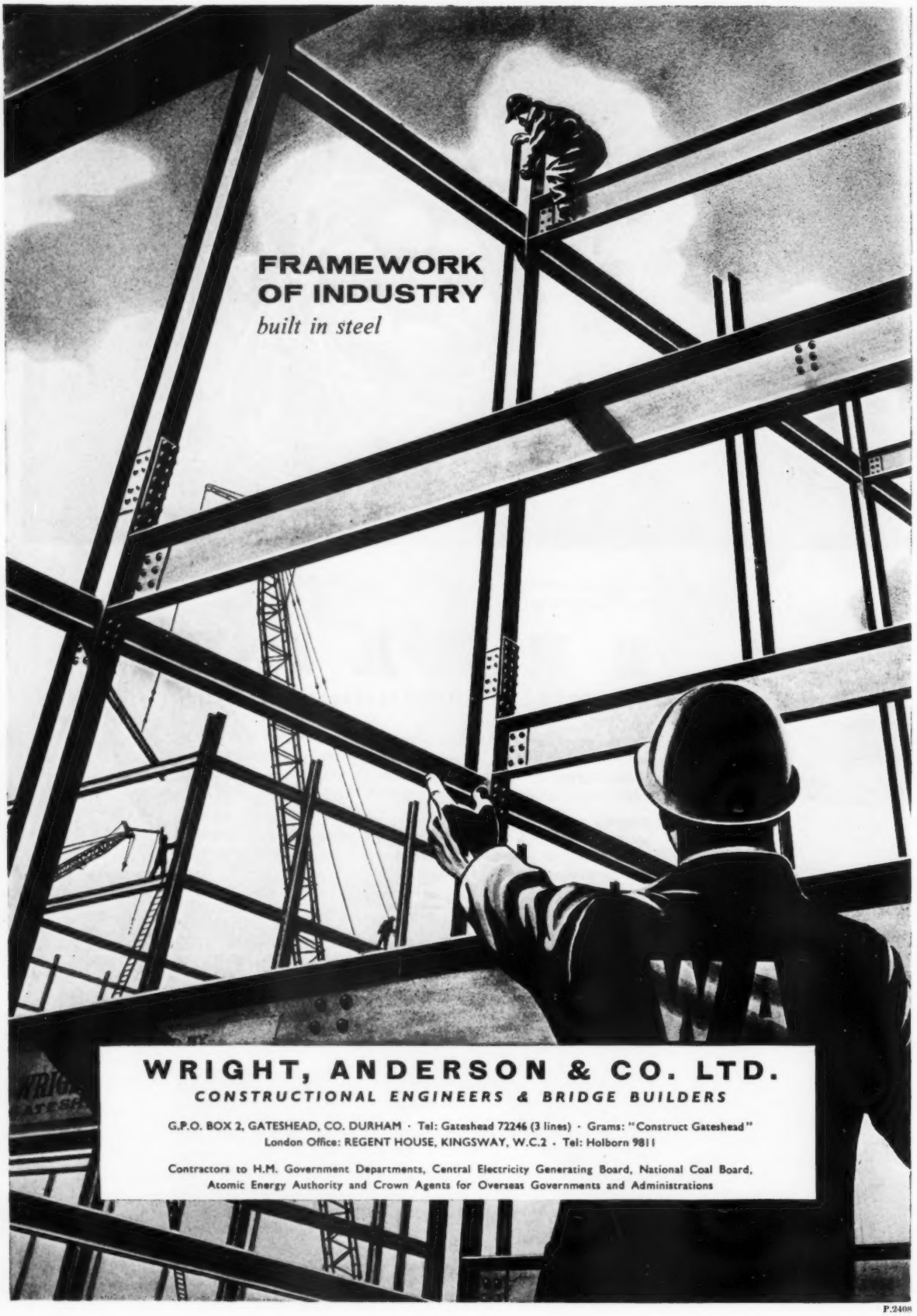

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TGA NP1

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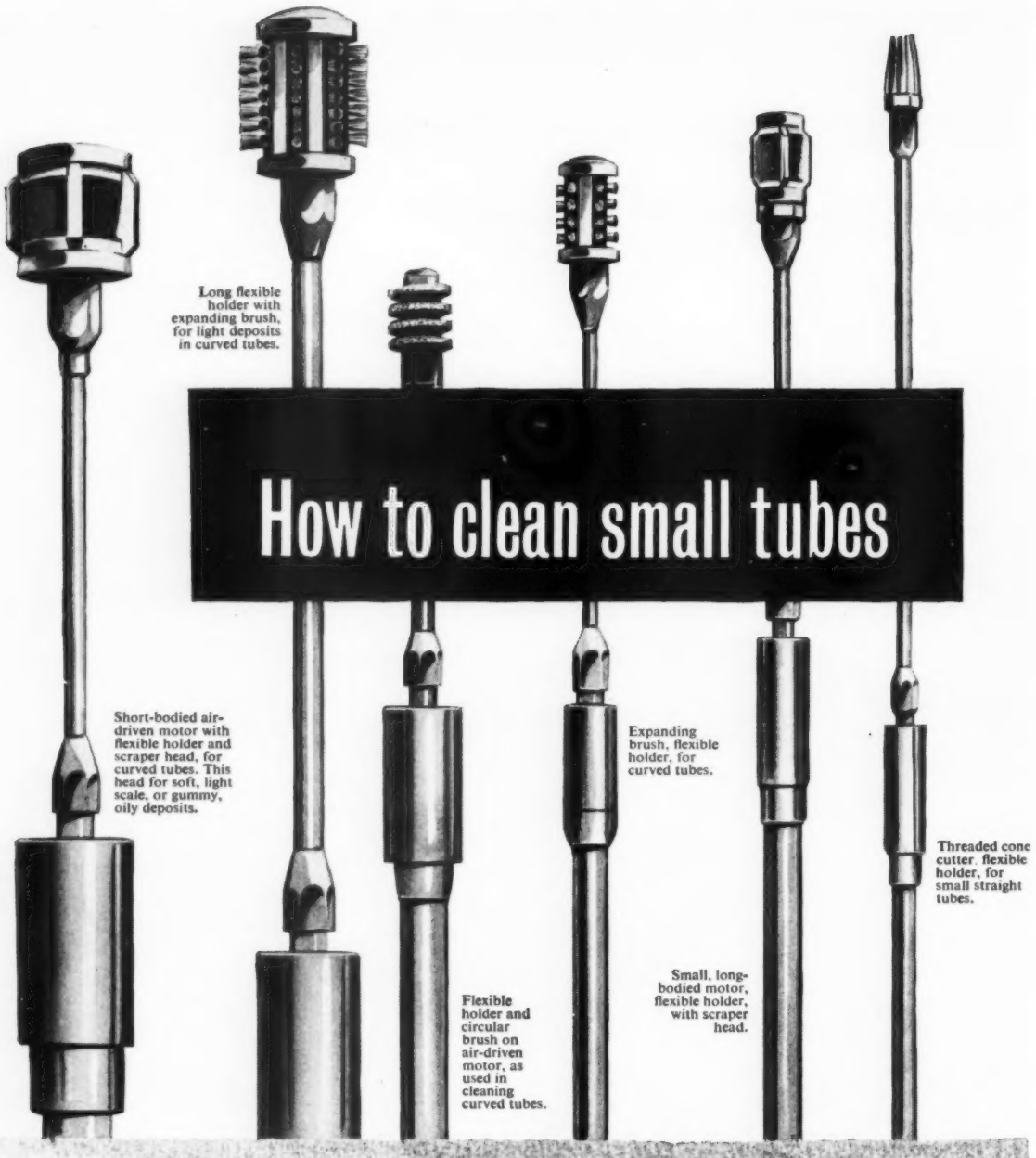
How to clean small tubes


Long flexible holder with expanding brush, for light deposits in curved tubes.
Short-bodied air-driven motor with flexible holder and scraper head, for curved tubes. This head for soft, light scale, or gummy, oily deposits.
Flexible holder and circular brush on air-driven motor, as used in cleaning curved tubes.
Expanding brush, flexible holder, for curved tubes.
Small, long-bodied motor, flexible holder, with scraper head.
Threaded cone cutter, flexible holder, for small straight tubes.

Long-bodied motor with universal joint and single-pin head, as used in straight tubes. This head for heavy deposits.

Long-bodied motor with direct-connected scraper head, for straight tubes.

It can be a tough business sometimes, doing a 100% job in cleaning small diameter tubes. The problem is designing a motor small enough to pass through the tube, particularly when it is curved. It is a problem that Lagonda has overcome. Look over the assortment of tools above, every one with proved performance. Write for the Lagonda Tube Cleaning Catalogue Y-48.

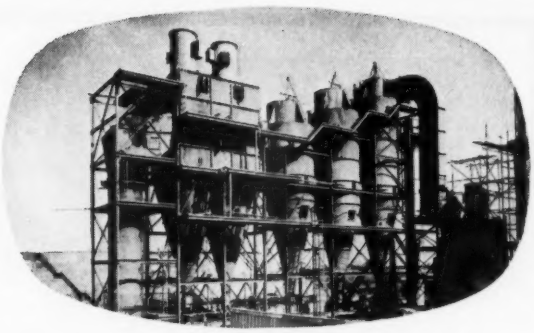
Lagonda TUBE CLEANERS

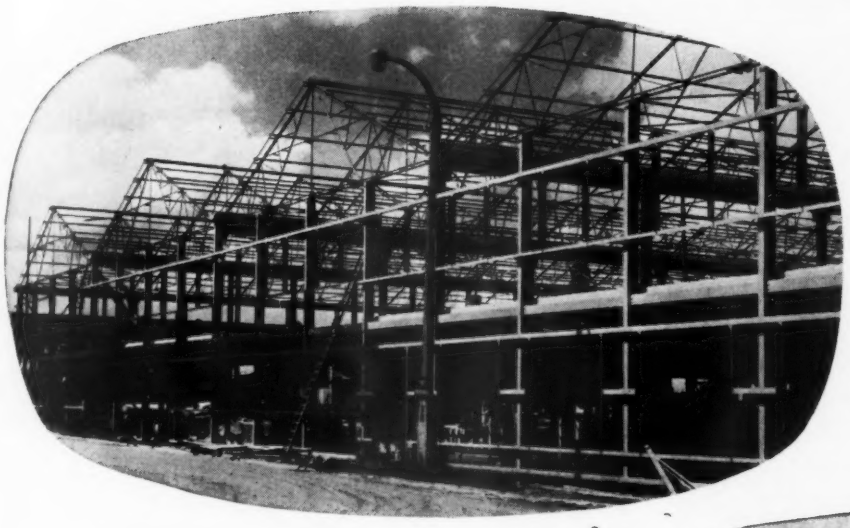
Consolidated Pneumatic

Made by CONSOLIDATED PNEUMATIC TOOL CO. LTD · DAWES ROAD · LONDON · S.W.6

CP 181

Structural Steelwork





Welding ▲

Site-welded cyclones and precipitators with supporting structures.

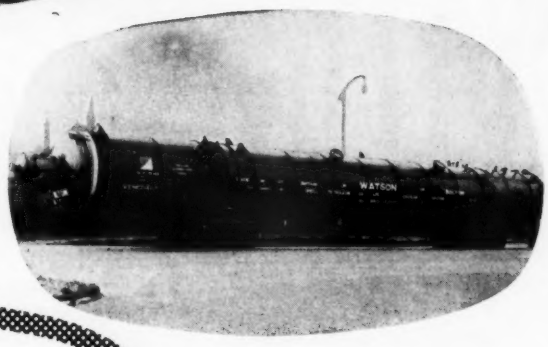
Pressure Vessels

Pressure Vessel for
Shell Petroleum Co. Ltd.
90ft. long, 9ft. dia.
All welds X-rayed.
Dead weight 40 tons. ▼

The photograph above shows part of a 2,000 ton Contract for U.K. Atomic Energy Authority, Springfields Plant, Preston.

Inspection facilities include laboratory equipped with up-to-date testing machines and radiography.

New bay on Works now completed — production area increased by 35,000 sq. ft.



STEELWORK

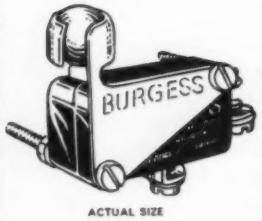
WATSON

BOLTON

Robert Watson & Co.
(CONSTRUCTIONAL ENGINEERS) LIMITED
Bolton, Lancs.
Telephone: Bolton 5125 (7 lines)
Telegrams: Watson, Telex, Bolton
and at London
Telephone: Belgravia 3785-7
and Bristol
Telephone: Filton 2361

O.K. – from any angle !

IT'S
Micro
Switchcraft



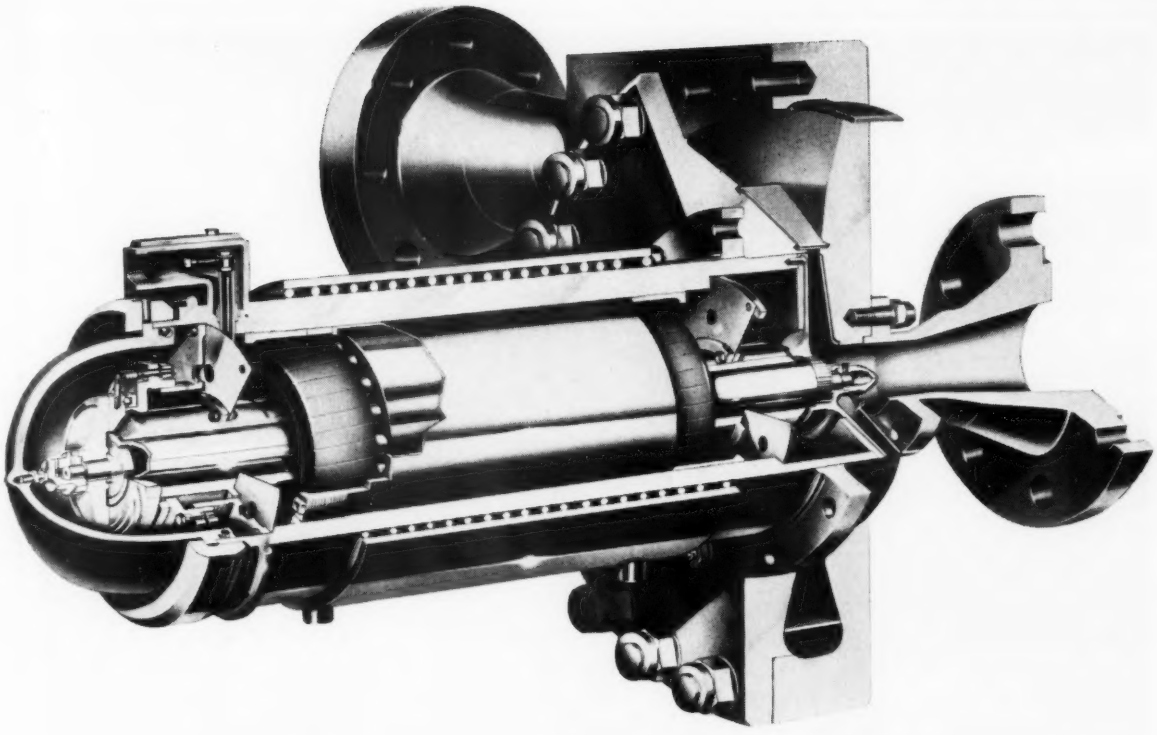
ACTUAL SIZE

THE BURGESS V3

Miniature Micro Switch with VAB Ball Actuator
will operate from any angle.

10 million operations minimum

BURGESS PRODUCTS CO. LTD, MICRO SWITCH DIVISION, DUKES WAY, TEAM VALLEY, GATESHEAD 11. Tel: Low Fell 75322. Telex: 53-229
127 Victoria Street, London SW1. Tel: Tate Gallery 0251 (3 lines)



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HAVE DESIGNED A RANGE OF GAS BEARING COMPRESSORS CAPABLE OF HANDLING GASES UP TO...

2,000 psi and 700°C

with input powers up to 2,000 hp.
They have many advantages
They are:
Free from lubricant contamination
Totally enclosed needing no mechanical seals
Practically maintenance free
Capable of operating over a wide range of temperatures and pressures

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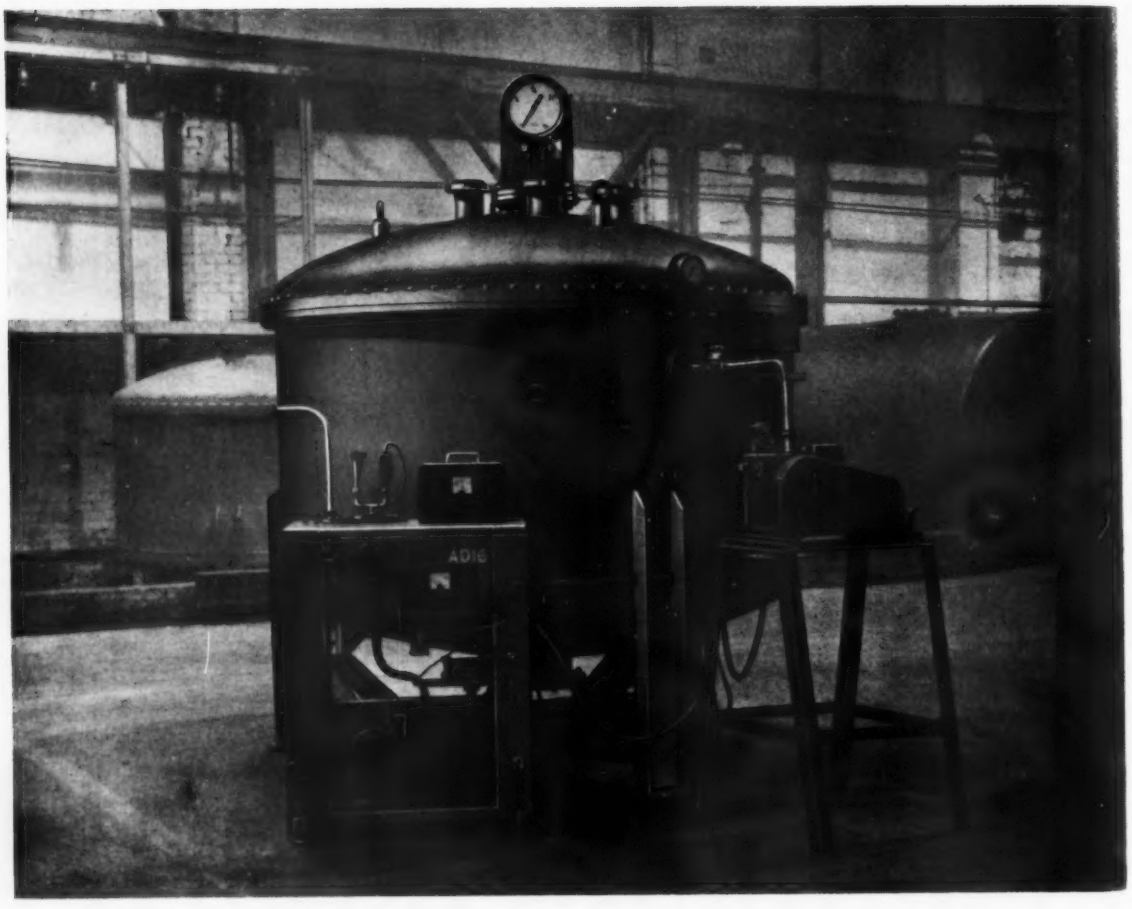

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in Stainless Steel, Mild Steel, Aluminium, Titanium

BUTTERFIELD craftsmen carry out welding with the latest and most up-to-date equipment, and at all stages of fabrication it is supervised by experts to any of the recognised codes. This includes the highest specification demanded by Nuclear Energy Establishments.

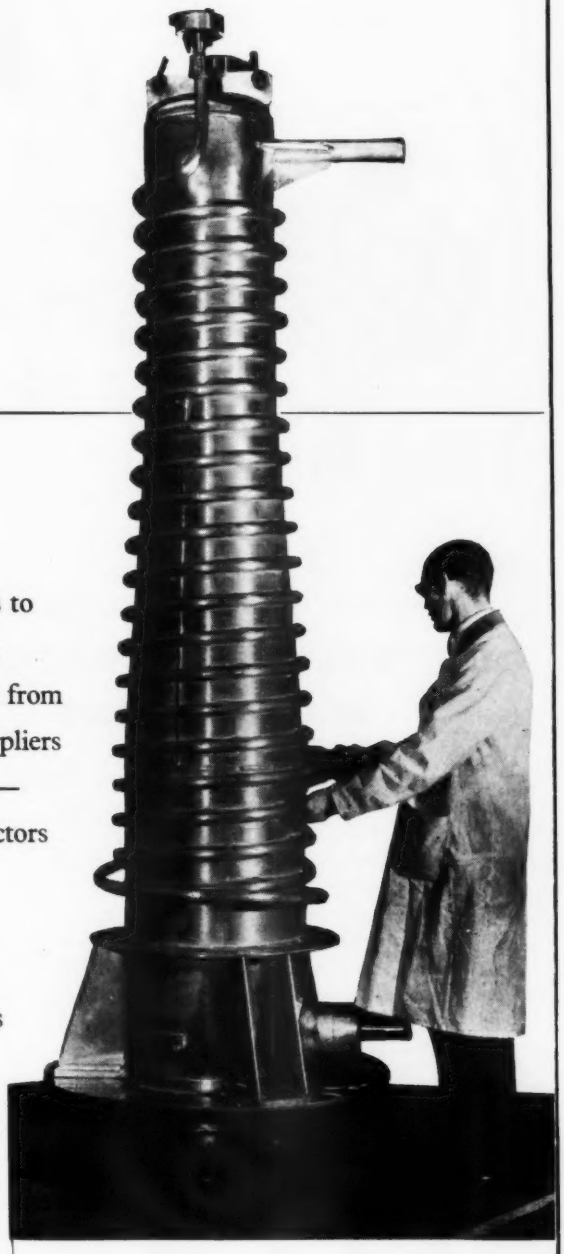
Butterfields of SHIPLEY

Illustrated: 2 tons capacity Liquid Oxygen Storage Tank. Inner vessel ½" × ½" thick 18/8 Ti stainless steel jacket ¾" × ½" thick mild steel. Jacket space filled with Expanded Perlite. Inner vessel tested 100 p.s.i. Jacket tested 30 p.s.i. for ·01mm. Hg. working vacuum. The illustration shows the vessel set up for vacuum tests for Air Products Limited for the Admiralty

W. P. Butterfield Ltd., P.O. Box 38, Shipley, Yorks. Tel. 52244 (8 lines) London & Branches.

Shaping the Future

Skill doesn't come easily. It has taken more than 12 years of close association with the development of Atomic Energy for Marstons to build up the specialized technical knowledge they possess in this field. Marston Excelsior, from the start, have been among the foremost suppliers of specialized equipment to the U.K.A.E.A.— plate type fuel elements for the research reactors Dido, Lido, and Dimple; gas coolers for Calder Hall, equipment of various kinds for ancillary plants. It is this past experience that is helping Marstons to shape the future with such precision.



Condenser (height 11′ 0″, mean diameter 2′ 0″) with body fabricated from $\frac{3}{8}$″ thick Kynal PA19 Aluminium Sheet, Argon Arc welded. Tube coil is made from 1″ N.B. Kynal P5 Aluminium Alloy, Argon Arc welded to the body.

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ICI **Fordhouses, Wolverhampton**

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MAR.235

OUR VALVES HAVE MANY FACES

Did you know that each one of our automatic control valves has a personality of its own? Take 'Safety Cut-out', for instance. Now, he's a careful type who shuts up like a clam whenever his electrical circuit is disturbed and flatly refuses to allow either liquids or gases to pass. Or there's 'Balanced 3-way'. This fellow is a leader and controls other chaps doing all the hard work — Pneumatic and Hydraulic cylinders for example. We have over 100 different 'types' of valves for every kind of automatic or remote control system involving water, steam, coal gas, oil, air and many other industrial liquids and gases. They don't use glands, stuffing-boxes or driving shafts and, what's more, they have a reputation for hard work, long life and the utmost reliability. Full technical details of this family of automatic control valves are contained in our new brochure No. 61. Why not write *NOW* for your copy?

Well over 100 of them, in fact. A 'type' to suit every requirement.

MAGNETIC VALVES ARE USED EXTENSIVELY IN

AIR CONDITIONING	LAUNDRY PLANT
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2 IMPORTANT DEMINERALISATION PLANTS

William Boby & Co. Ltd. have been entrusted with the execution of the demineralisation water treatment plants at:

1 CHEMSTRAND LTD., N. Ireland

(Main Contractors: Messrs. Constructors John Brown)

For their new 'ACRILAN' factory at Coleraine, N. Ireland, Messrs. Chemstrand have installed a 10,000 galls./hr. 'Boby' demineralisation plant for process and boiler feed water.

The plant comprises the following sections:

Coagulation and Settlement — Filtration — Cation Exchange — Weakly basic Anion Exchange — Degassing — Mixed Bed Ion Exchange.

2 VEITSILUOTO O/Y, Finland

The Veitsiluoto paper mills of Finland have installed a 13,400 galls/hr. 'Boby' demineralisation water treatment plant for feed water for boiler working at 1,750 p.s.i.

The plant comprises the following sections:

Coagulation and Settlement—Filtration—Cation Exchange —Weakly basic Anion Exchange — Strongly basic Anion Exchange.

WATER **BOBY** TREATMENT

Established in 1875

WILLIAM BOBY & CO. LTD.

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Looking to the future...

The world is making rapid scientific and technological progress but man's thirst for knowledge is insatiable. New methods of power are being developed and we have entered the nuclear age in the hope that these discoveries will help to secure a higher standard of living for all of us. But the need for fuel economy remains; that is why more and more industrial concerns are turning to Kenyon Planned Heat Insulation.

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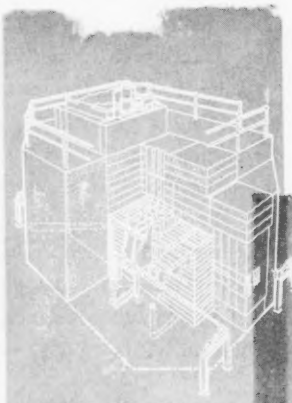
CHOOSE FROM 3 BASIC *low-power* REACTOR TYPES

No "compromise" with AMF:

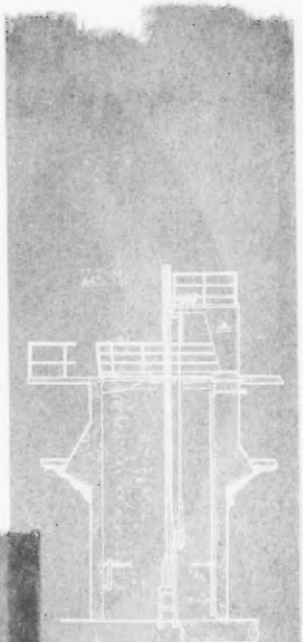
In the field of low-power training and research reactors, AMF offers you a choice of *three* basic reactor types,* not just one standard model which of necessity represents a compromise in fulfilling the needs for varied applications. Starting with any one of the three basic, proven types, AMF custom-designs your reactor to meet your requirements, whatever they may be.

Some typical applications include isotope production, exponential studies, reactor technology, and research in the fields of biology, metallurgy, chemistry, medicine, agriculture, etc.

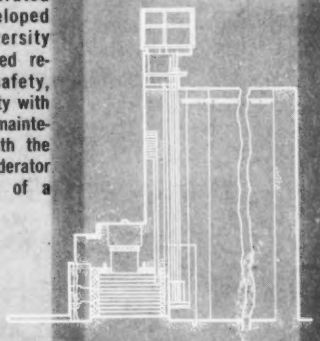
**none of which require containment; any ordinary building may be utilized.*



AMF-GNE "Educator" Training Reactor—an advanced graphite and water moderated training reactor developed specifically for university training and associated research. Combining safety, simplicity and flexibility with ease of operation and maintenance, it provides both the safety of a water moderator and the convenience of a solid moderator.



AMF Light-Water Tank-Type Reactor — combines inherent safety with a maximum of experimental facilities; designed to provide the high flux levels frequently called for in certain fields of basic and applied research. Highly compact, the reactor allows a minimum building size, contributing importantly to economy of space and construction costs.



AMF Pool-Type Reactor—fundamental in concept and flexible in application, it consists essentially of a core submerged in an open pool of water with irradiation facilities built into the pool shell. Core visibility offers a system ideally suited to both research and training while assuring complete safety.

AMF, a world leader in nuclear engineering and manufacturing, is FIRST among research reactor builders, with these sixteen projects either completed or presently under construction:

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"Het Atoom" Exhibition, Amsterdam, Netherlands
Technische Hochschule (Munich Technical University), Munich, Germany
Industrial Reactor Laboratories, Inc., Plainsboro, New Jersey
McMaster University, Hamilton, Ontario, Canada
Japanese Atomic Energy Research Institute, Tokai Mura, Japan
University of Florida, Gainesville, Florida
Greek Atomic Energy Commission, Aghia Paraskevi, Greece
Union Carbide Nuclear Corporation, Sterling Forest, New York
Portuguese Atomic Energy Commission, Lisbon, Portugal
Societa Ricerche Impianti Nucleari, Milan, Italy
University of Buffalo, Buffalo, New York
Israeli Atomic Energy Commission, Rehovoth, Israel
Austrian Study Group for Atomic Energy, Vienna, Austria
University of Teheran, Teheran, Iran
U. S. Atomic Energy Commission, University of Puerto Rico, Mayaguez, Puerto Rico

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American Machine & Foundry Company

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Manufacturing subsidiaries and sales offices: LONDON · GENEVA · BOLOGNA · SÃO PAULO · TOKYO

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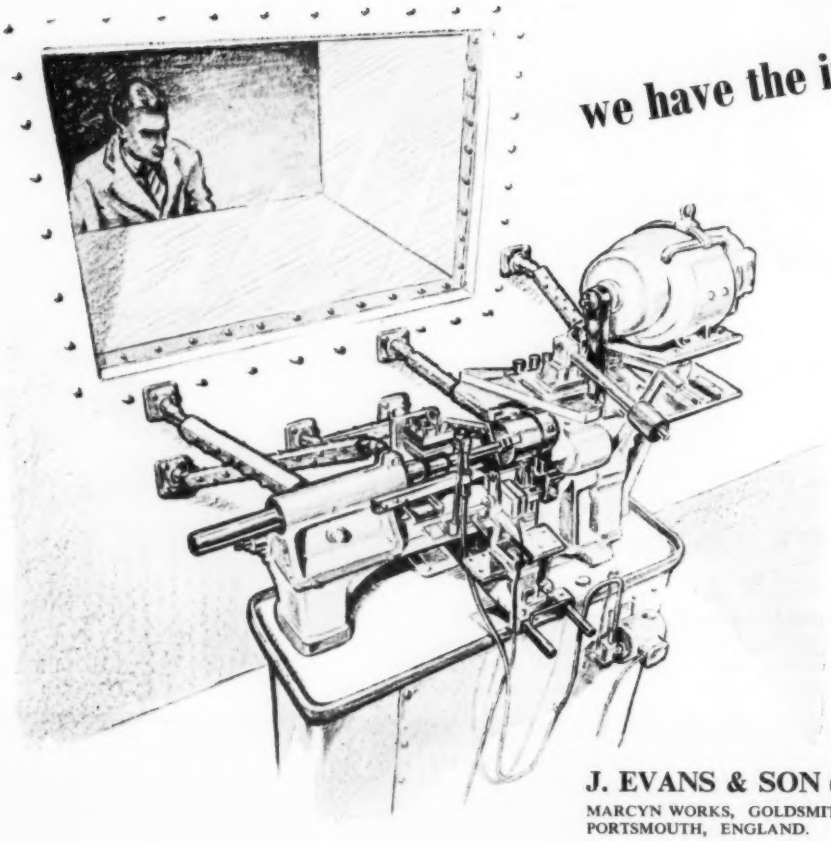
for remote-controlled machines...

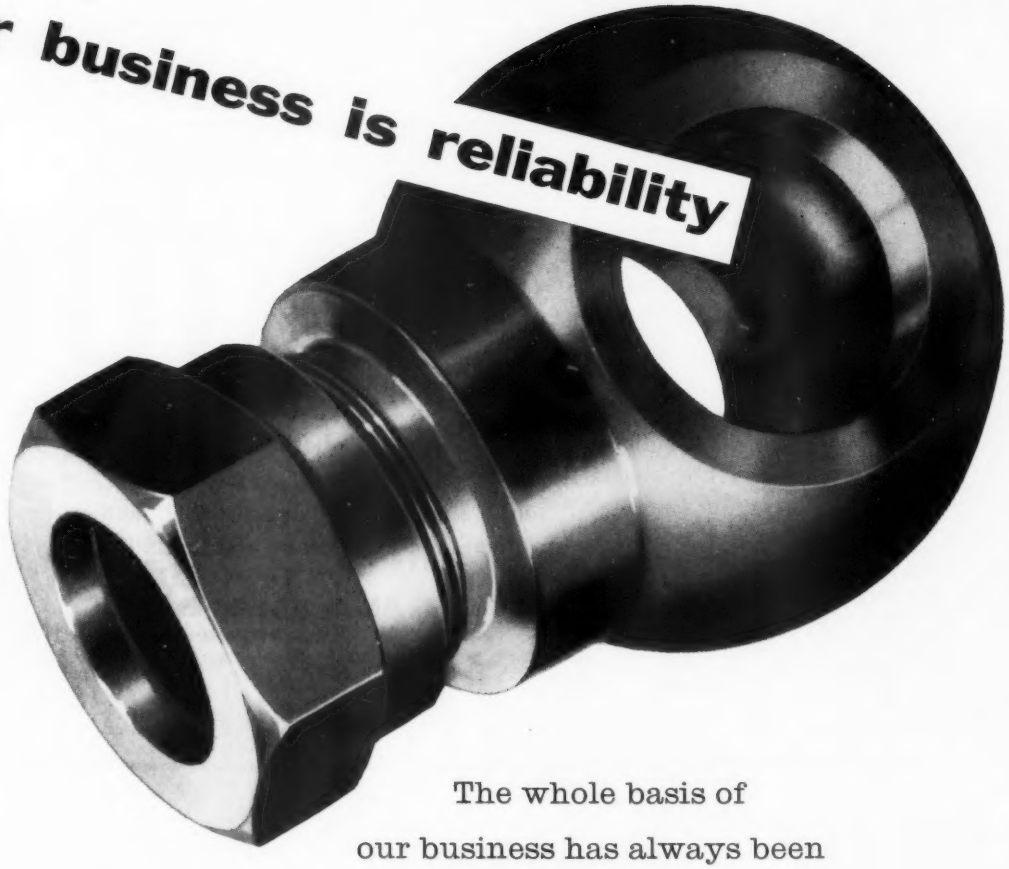
We are in the unique position through our long experience as designers and builders of special purpose machinery and precision machine tools, to offer *practical* equipment for the machining and handling of radio-active materials.
One of the many special projects carried out by us is the remotely controlled lathe (illustrated below) for the machining of tensile test specimens from irradiated uranium for Dounreay fast breeder reactor. Equipment for the nuclear field can only be entrusted to people who know the problems ! Visit us in Portsmouth where selected films and a most interesting range of activities can be shown.



we have the inside story

J. EVANS & SON (PORTSMOUTH) LTD.
MARCYN WORKS, GOLDSMITH AVENUE,
PORTSMOUTH, ENGLAND. Tel. 32233.

Our business is reliability



The whole basis of
our business has always been
to supply high pressure fittings
which will guarantee the
reliability of pipe line systems.
Experience of high pressure problems
has brought with it the large range of
fittings now produced by ERMETO.

Details of high pressure couplings and valves will be sent on request.

ERMETO
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BRITISH ERMETO CORPORATION LTD

HARGRAVE ROAD · MAIDENHEAD · BERKS Telephone: Maidenhead 5100 (10 lines)

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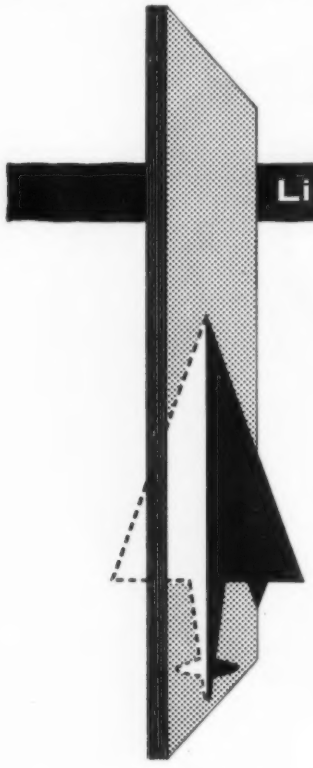

Light * strong * corrosion-resistant

TITANIUM

Most people concerned with metals know what it is but not everyone is aware of what it can do. If you feel that you should know more about this light, strong and corrosion-resistant metal, then write for brochure on properties and forms to:

TITANIUM METAL & ALLOYS LTD
2 METAL EXCHANGE BUILDINGS
LONDON E.C.3. TEL: MANSION HOUSE 4521
WORKS: SHEFFIELD
"ROLLERS OF MODERN METALS"

MILNE for welding & cutting equipment

All Milne equipment is designed by practical engineers who know the exact requirements of the Welding and Allied Industries. It includes Brazing, Welding and Cutting Blowpipes, Regulators to suit every purpose, Cutting and Profiling Machines, Gas Economisers, Valves for Pipe Lines and other necessary welding accessories.

To provide a comprehensive welding service Milne also offer Electric Arc and Resistance Welding Plant and Equipment.

For full information and details write to:-

C. S. MILNE & CO. LTD.

Manufacturers of Gas Welding and Cutting Plant and Equipment
Stockists and Suppliers of Electric Arc Resistance Welding Equipment

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Telephone: Tideway 3852

Also at 172/174 West Regent Street, Glasgow, C.2

TIB 112

Coles specification meets
Nuclear Power demands
COLES' 80 years of specialised experience in the production of Cranes has put them years ahead. Developed to serve Britain's future needs, the new COLES Cranes are as modern as your industry they serve.
Send now for the latest Coles literature.
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COLES
DIESEL-ELECTRIC CRANES
CAPACITIES 5 TO 50 TONS

Designed, manufactured and marketed by:—

STEELS ENGINEERING PRODUCTS LIMITED, Sunderland, England. *Tel: 56281 (10 lines) Grams: Steel, Sunderland.*
SALES AND SERVICE: **Birmingham:** 39 Thorp St., 5. **Glasgow:** 235 Bath St., C.2.
London: 143 Sloane St., S.W.1. **Manchester:** 153 Oxford Rd., 13. **Newcastle:** Worswick Chambers, Worswick St., 1.

COLES THE NAME THAT CARRIES WEIGHT

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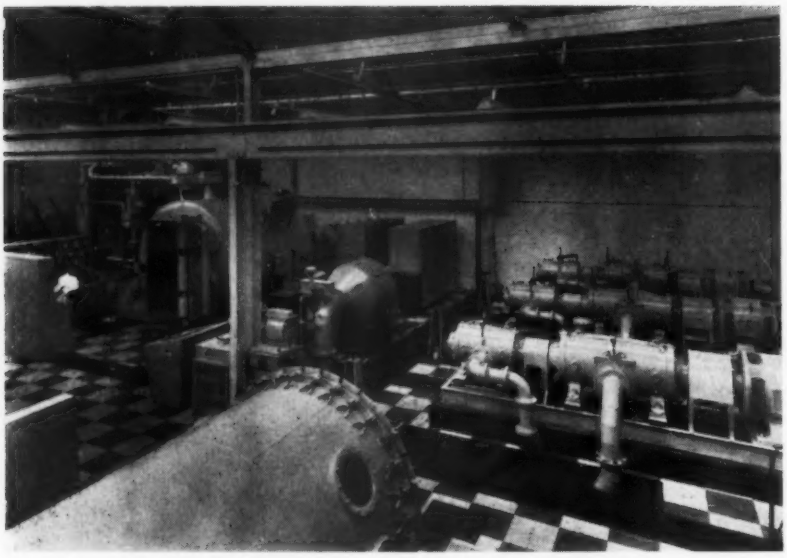

Part of the English Electric Aircraft Equipment Laboratories with three HOLLAND/SLM 2-stage rotary vacuum pumps exhausting the altitude test chamber.

HOLLAND / SLM

ROTARY COMPRESSORS AND VACUUM PUMPS

GIVE SERVICE FOR TO-DAY FOR TO-MORROW AND FOR YEARS AHEAD

The B. A. Holland Engineering Co. Ltd.

LINDO LODGE, STANLEY AVENUE, CHESHAM, BUCKS.

Telephone: Chesham 8406/8 Telegrams: Picturable, Chesham Works: SLOUGH, BUCKS

Don't bury your head...

. . . in the sand and take a Pressure Gauge at its 'face' value. Look for the name 'P & G' and be certain of an instrument of quality—made by craftsmen for complete accuracy and dependability over years of active service. The range of P & G pressure gauges includes many different types to suit most applications —vacuum, combined, altitude, electric contact, differential, critical, duplex, diaphragm, capsule, etc.

Write for publication No. 87

Payne & Griffiths Ltd

WINDMILL

TUDOR WORKS · WINDMILL LANE
SMETHWICK · BIRMINGHAM

HINKLEY POINT

first 500,000 kW atomic power station

The construction of Hinkley Point, the first atomic power station in the world designed to produce electricity at a cost comparable with that from conventional power stations, marks a great step forward in the peaceful utilisation of atomic power.

Operations on site and at the works of the Group companies, are making rapid progress. Already the shape of this great new station is revealed by a complex of approach roads, vast excavations and massive foundations. Soon the new harbour being built will be handling the full flow of plant and equipment from the Group factories, for the biggest constructional task of this atomic age.

THE ENGLISH ELECTRIC COMPANY Limited, Marconi House, Strand, London, W.C.2.

BABCOCK & WILCOX LIMITED Babcock House, Euston Road, London, N.W.1.

TAYLOR WOODROW CONSTRUCTION Limited, London

ENGLISH ELECTRIC | BABCOCK & WILCOX | TAYLOR WOODROW

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'HYDROBORD'

for

NEUTRON SHIELDING

HYDROBORD provides insulation against Fast and Thermal Neutrons or combinations of both.

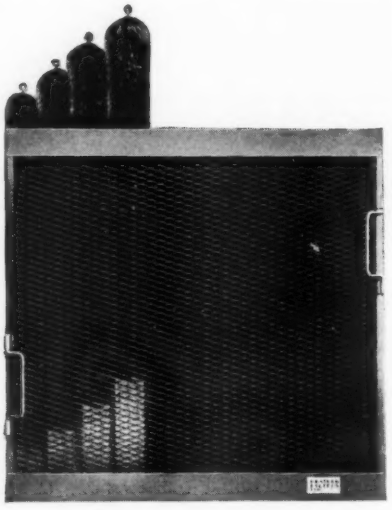
William Mallinson and Sons Ltd.

130 HACKNEY ROAD · LONDON · E.2

Telephone: Shoreditch 7654 Telegrams: 'Almoner', London

YOU DON'T NEED SPECIAL EQUIPMENT OR FLUIDS TO CLEAN THIS AIR FILTER!

Heather Multi-Brush Air Filters can be cleaned easily and thoroughly, without special equipment or fluids, and still retain the initial filtering efficiency. In fact, maximum efficiency and minimum maintenance is the correct way to sum up this unique, low-cost filter system.



A finely graded mesh of intermingling hair, specially selected to withstand the varying humidity and conditions of the dust-laden air, is used to trap impurities and dust particles from the incoming air stream. Periodically, the filter brushes can be cleaned simply by shaking or suction cleaning.

** Write NOW for leaflet H39 which gives full details.*

HF

HEATHER FILTERS LIMITED

7 KENDALL PLACE . BAKER STREET . LONDON . W.I HUNTER 1801

HF.2

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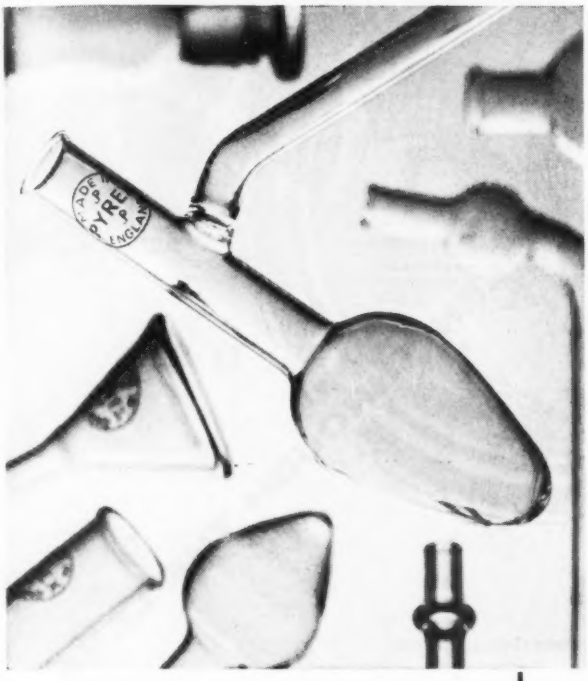
It's a somewhat smaller world



Though the scientific world is enlarging in all directions, especially in schools, the trend of apparatus is in the opposite direction: towards somewhat smaller, neater, cheaper, safer — in fact, Semi-micro — equipment. Especially in schools. Pyrex have given much thought to designing a Semi-micro range that is simple without being over-rigid, yet covers the widest field of routine experiments. Needless to say, all parts are made to strict specification to allow for interchangeability: this attention to detail explains why Pyrex is the most popular and widely used laboratory and scientific glassware

Pyrex semi-micro apparatus

is made from the same borosilicate glass as other PYREX laboratory and scientific glassware. It therefore

withstands thermal shock
resists chemical attack
has exceptional mechanical strength

Saves costs — smaller quantities of reagents are used

Safer — less danger from explosions and toxic fumes

More experiments can be carried out in a given period

Saves space — less working space, less storage space needed

Develops manipulative techniques — students acquire skill in handling small quantities of reagents

Comparatively low initial cost — and being PYREX, it vastly reduces replacement costs

Assemblies can be economically made up using rubber tubing and bark corks

● Ask for a catalogue from

PYREX
Regd. Trade Mark BRAND

MADE IN ENGLAND PYREX

Laboratory and scientific glass

INDUSTRIAL SALES DIVISION JAMES A JOBLING & CO LTD Wear Glass Works Sunderland

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They shall not pass!

'They shall not pass' in liquid or gas
Is the cry of Porous Ceramic.
Impurities fall as they reach my wall,
No matter how bold or dynamic.

No grit or dust, corrosion or rust
Has a chance of penetration,
The smallest article, crystal or particle
Is thwarted from infiltration.

Here is the filter, the finest de-silter
Of murky liquid and gas,
Wherever they've been, until they come clean
They're never allowed to pass.

All night and day, I work away,
My duty to strain without strain;
Thus at low cost, materials lost,
Are turned to profit and gain.

Write for Porous Ceramic Catalogue No. 10

DOULTON INDUSTRIAL PORCELAINS LIMITED

DEPT. NP, WILNECOTE, TAMWORTH, STAFFS., ENGLAND

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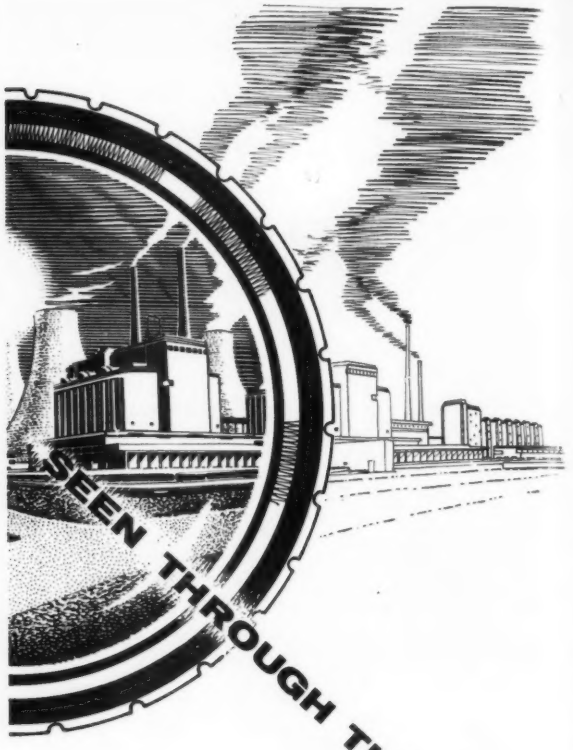

Seen through the lens
of camera and projector,
many hidden facets of industry
come into focus — when Turners'
operators put them in the picture.
Public relations, staff recruitment and
training, publicity, selling and
many other problems respond to their
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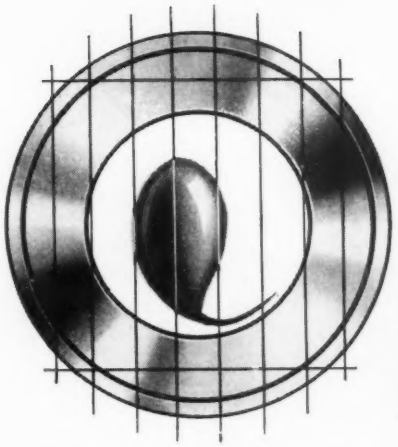

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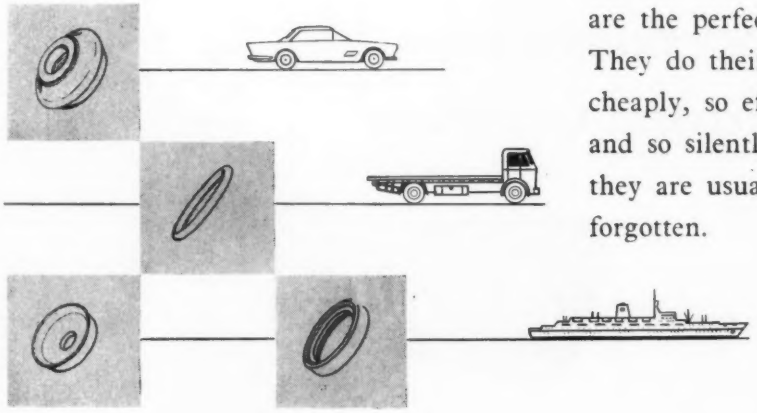
is a difficult prisoner...

and it must be kept in solitary confinement too; no fraternisation with that insidious enemy dirt, either. SuPerfect Oil Seals are the perfect goalers. They do their job so cheaply, so efficiently, and so silently that they are usually completely forgotten.



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Manufacturers of 'SuPerfect' Hydraulic Packings and 'O' Rings; 'Romet' water pump seals and mechanical pump seals; 'Aeroquip' Flexible Hose with detachable re-usable fittings; 'Fidrac' mechanical rubber mouldings; 'Redcaps' Polythene Protective Caps and Plugs.

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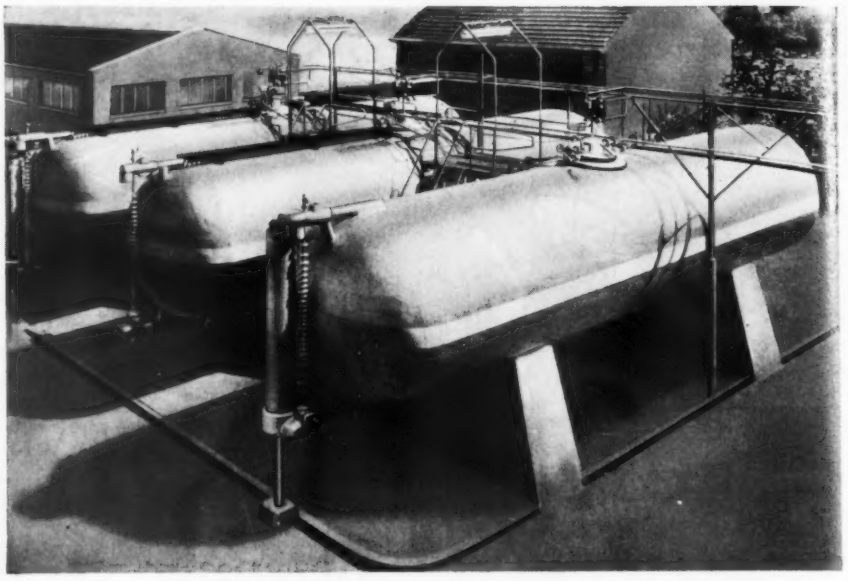
CO_2



This illustration shows a storage installation for 150 tons of Liquid CO_2 at low pressure.

We supply complete installations including Vapourisers for large scale CO_2 discharge, automatic apparatus and control instruments.

We also supply liquid and solid CO_2 production plants from a variety of fuels or from by-product gases with capacities of ½-ton per day upwards with guaranteed purity of the CO_2 produced.

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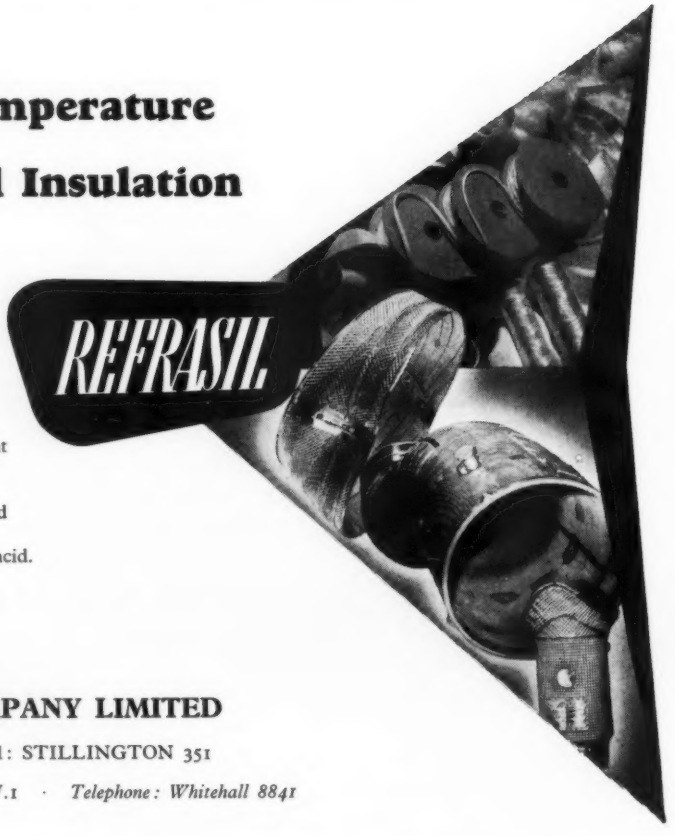

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The Metropolitan-Vickers Range of Scientific Equipments includes apparatus for the investigation of metallurgical, chemical and biological problems in research, production or processing. These equipments cover a wide selection of specialised scientific apparatus.

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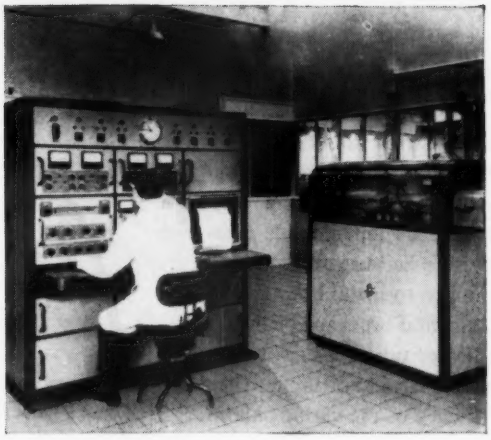
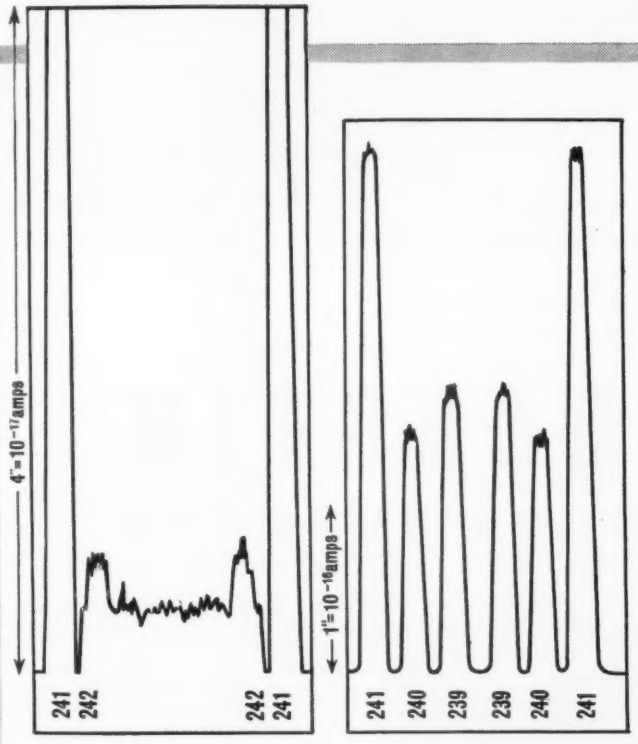


MASS SPECTROMETER TYPE MS5 *An instrument specially designed for the measurement of isotope ratios of inorganic solids by the surface ionisation technique.*



ANALYSIS OF PLUTONIUM

m/e	239	240	241	242
% ABUNDANCE	27·20	23·10	49·60	0·072
STANDARD DEVIATION	0·25	0·30	—	0·007

Tabulated results and traces from sample of approximately 10^{-8} grams of plutonium nitrate, using the triple filament technique and the multiplier detector. The standard deviation quoted is taken on 10 measurements.

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The Ekstrom liquid level indicator shown here is indicating the level of liquid butane in a storage tank at the Luton Works of Messrs. Vauxhall Motors Ltd.

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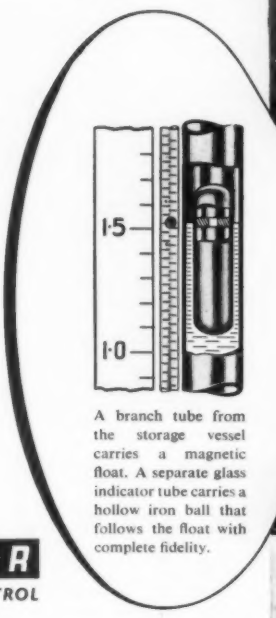

A branch tube from the storage vessel carries a magnetic float. A separate glass indicator tube carries a hollow iron ball that follows the float with complete fidelity.

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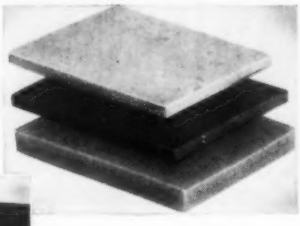

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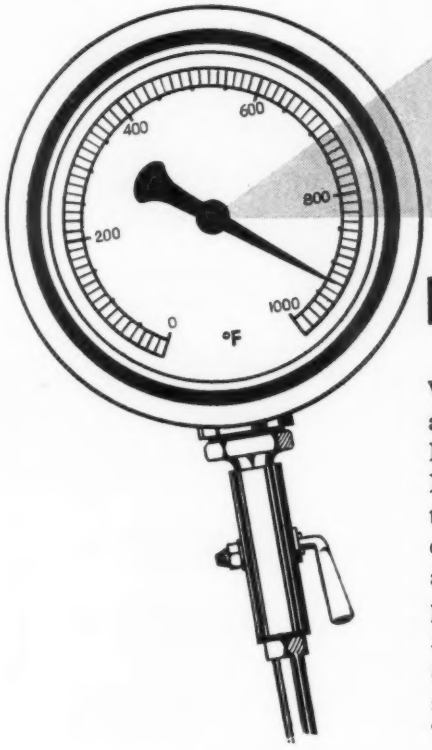

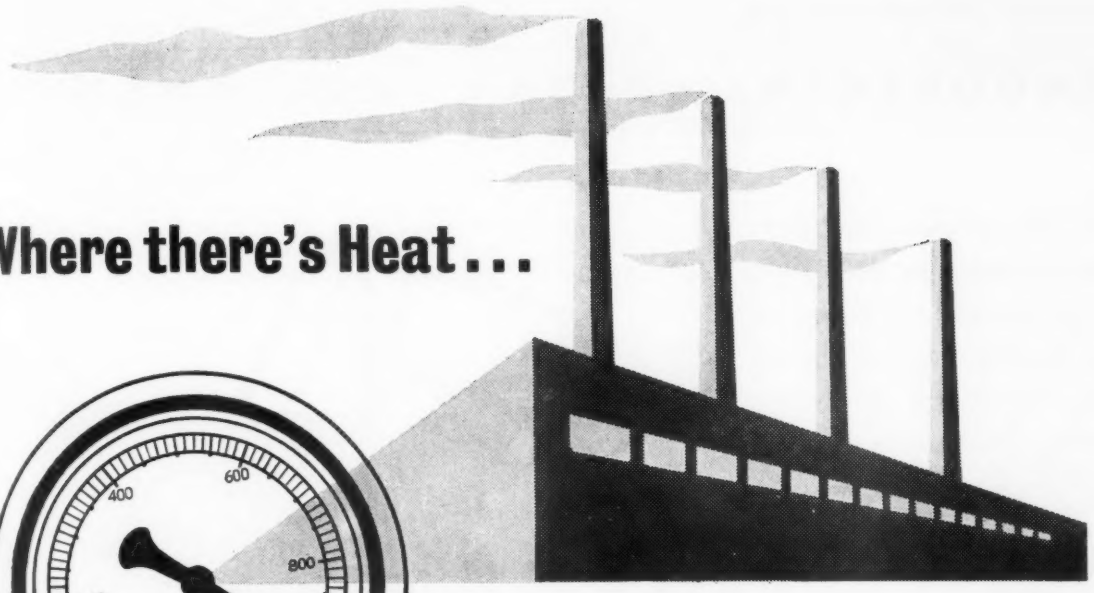

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When heat plays a part in production — whatever the industry and equipment employed — there is the need for BPL Heat Resisting Paints for the protection and decoration of plant. Furnace doors and boiler-room equipment, surfaces of high temperature reaction vessels, smoke stacks, foundry plant, exhaust manifolds; these are examples of quite usual applications, but perhaps your particular industry has unusual problems to be solved.

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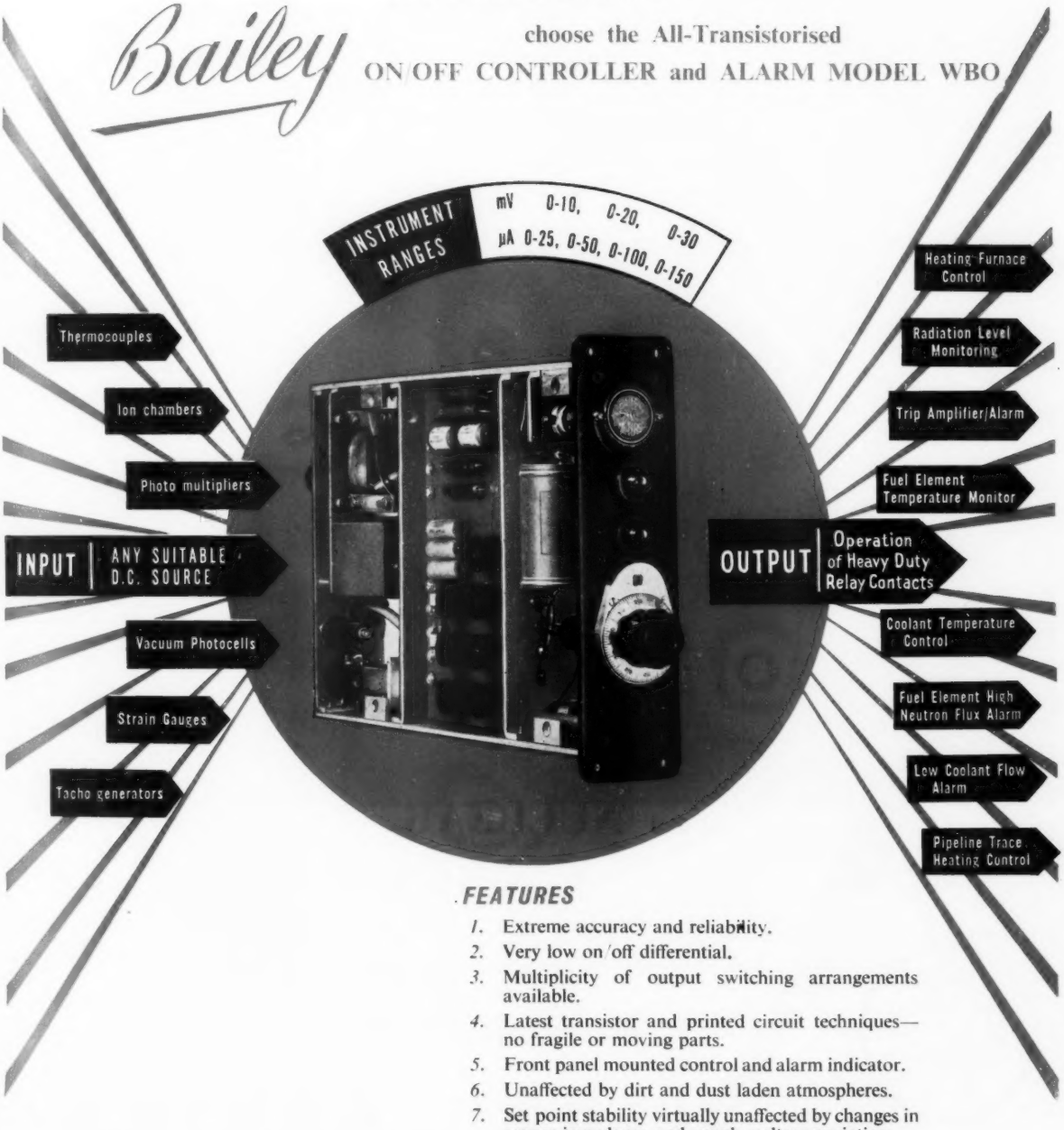

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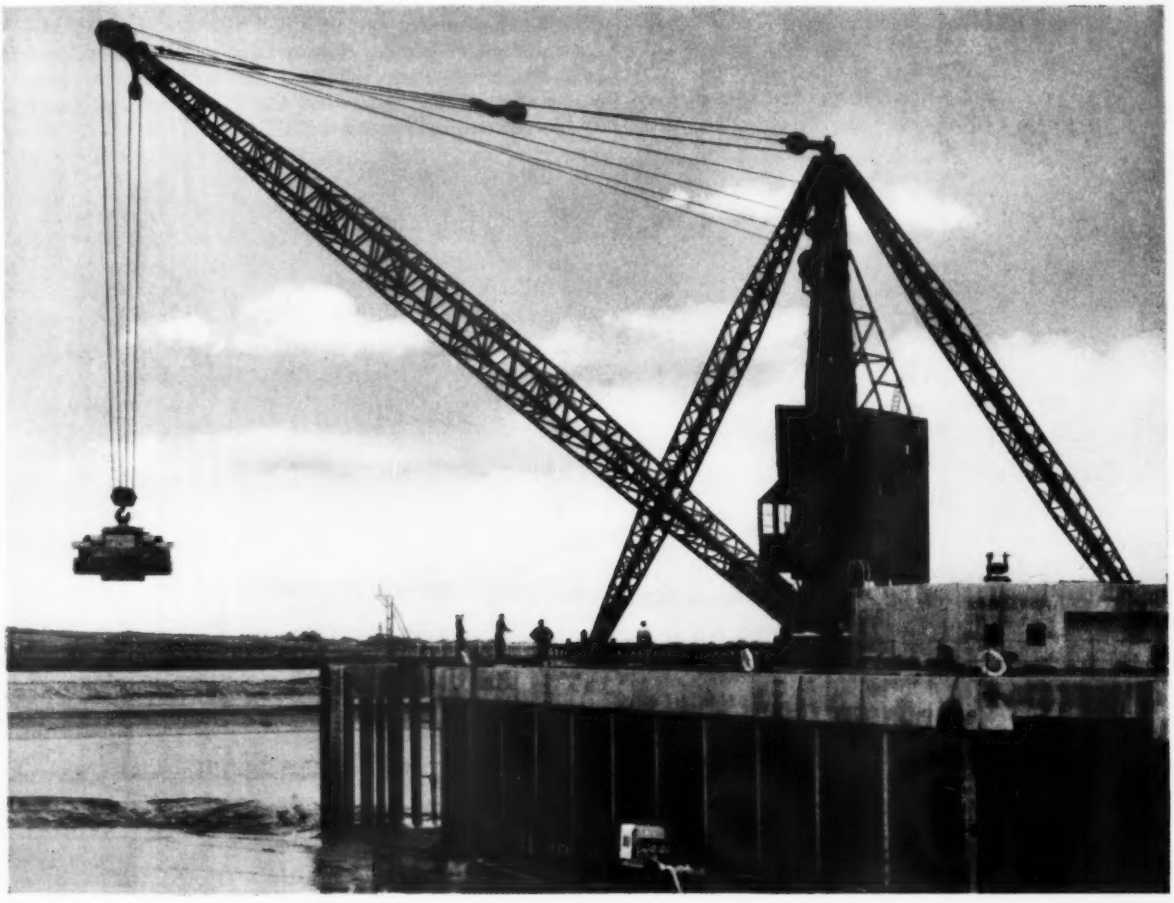
Two Butters 45 ton Derrick Cranes are in service at Hinkley Point . . .



Both were supplied to the order of Babcock and Wilcox Ltd.

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The cranes are of the three motor type, with a separate motor for each motion.

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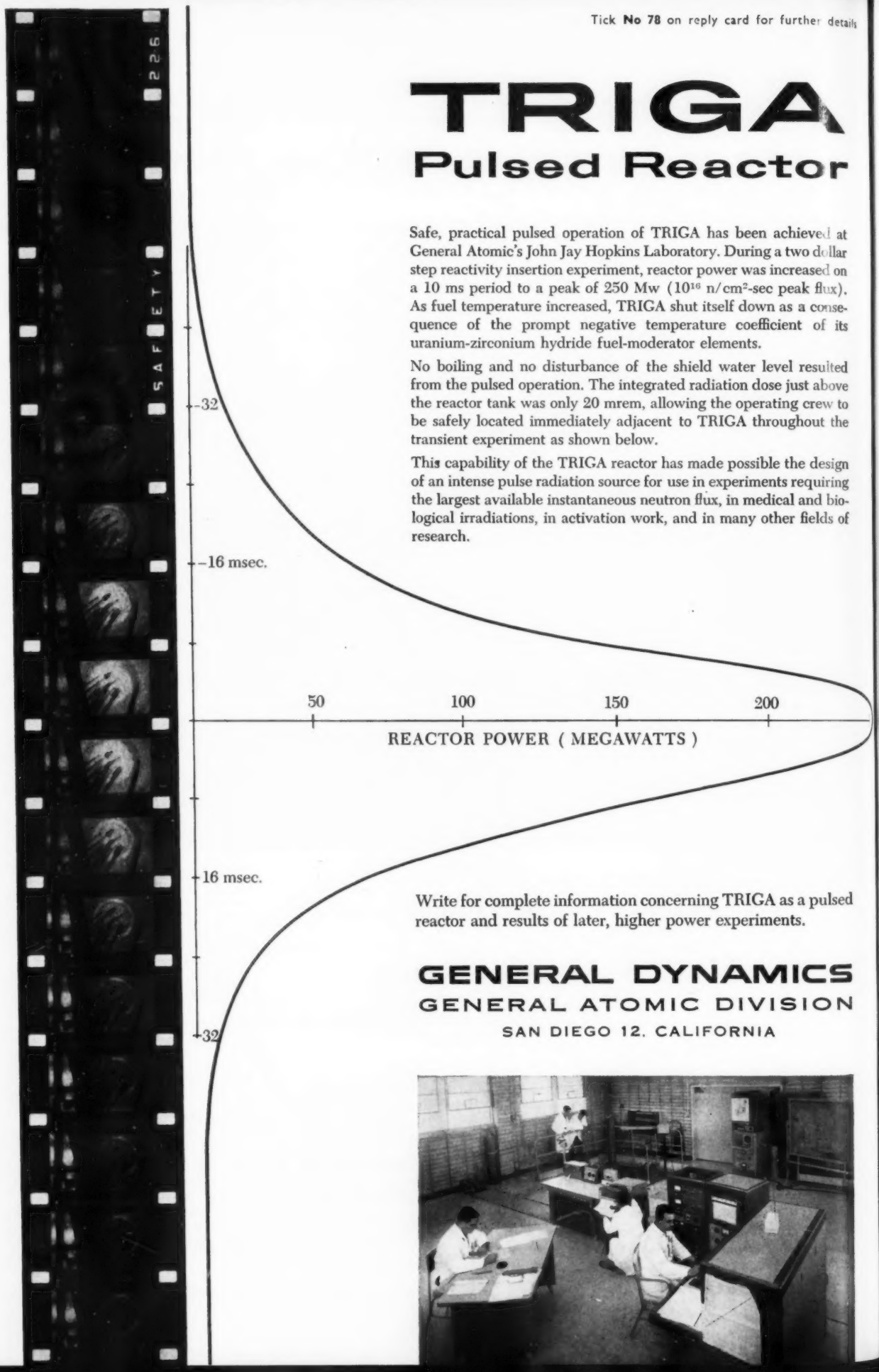
TRIGA
Pulsed Reactor

Safe, practical pulsed operation of TRIGA has been achieved at General Atomic's John Jay Hopkins Laboratory. During a two dollar step reactivity insertion experiment, reactor power was increased on a 10 ms period to a peak of 250 Mw (10^{16} n/cm²-sec peak flux). As fuel temperature increased, TRIGA shut itself down as a consequence of the prompt negative temperature coefficient of its uranium-zirconium hydride fuel-moderator elements.

No boiling and no disturbance of the shield water level resulted from the pulsed operation. The integrated radiation dose just above the reactor tank was only 20 mrem, allowing the operating crew to be safely located immediately adjacent to TRIGA throughout the transient experiment as shown below.

This capability of the TRIGA reactor has made possible the design of an intense pulse radiation source for use in experiments requiring the largest available instantaneous neutron flux, in medical and biological irradiations, in activation work, and in many other fields of research.



Write for complete information concerning TRIGA as a pulsed reactor and results of later, higher power experiments.

GENERAL DYNAMICS
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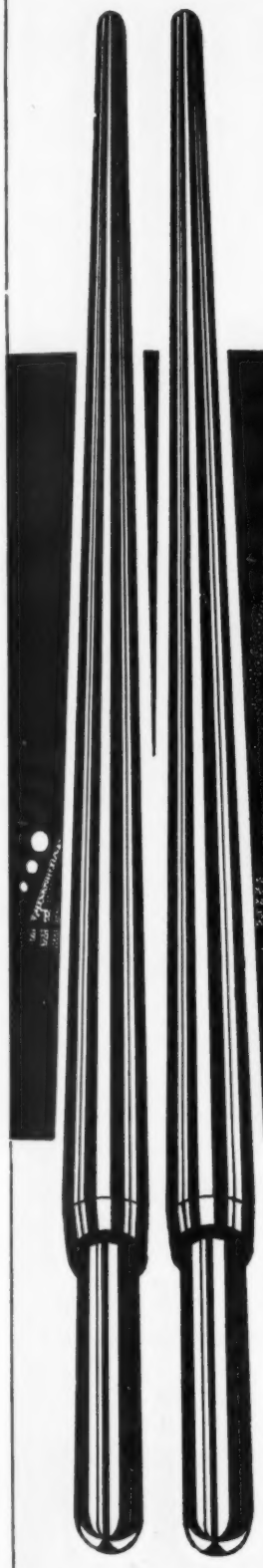
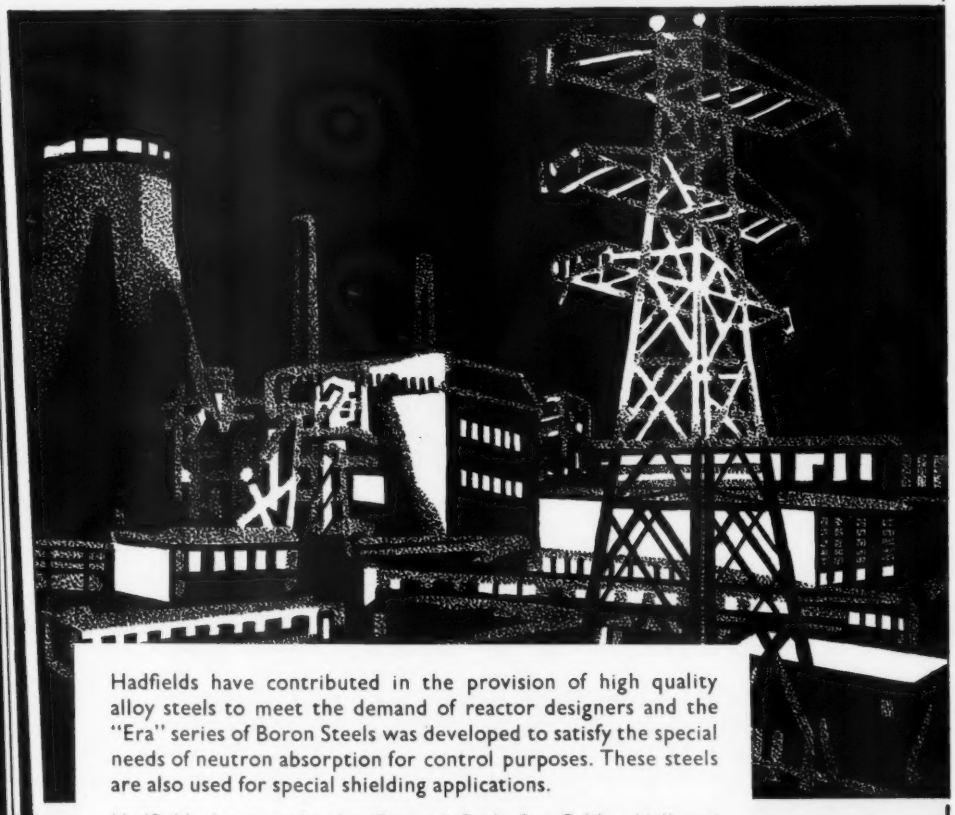
One of the most essential characteristics implied by the expression 'high quality' is reliability, and the construction of nuclear power plants ranks high amongst those advanced engineering projects, where any doubt concerning the materials of construction cannot be tolerated





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Hadfields have made the Control Rods for Calder Hall and Chapelcross Stations of U.K.A.E.A., incorporating "Era Boron Steels" and "Era H.L.C." special Low Cobalt Stainless Steel. "Era H.L.C." Steel has also been used in the production of a number of other reactor components and is of the 18/8 Stabilised type.

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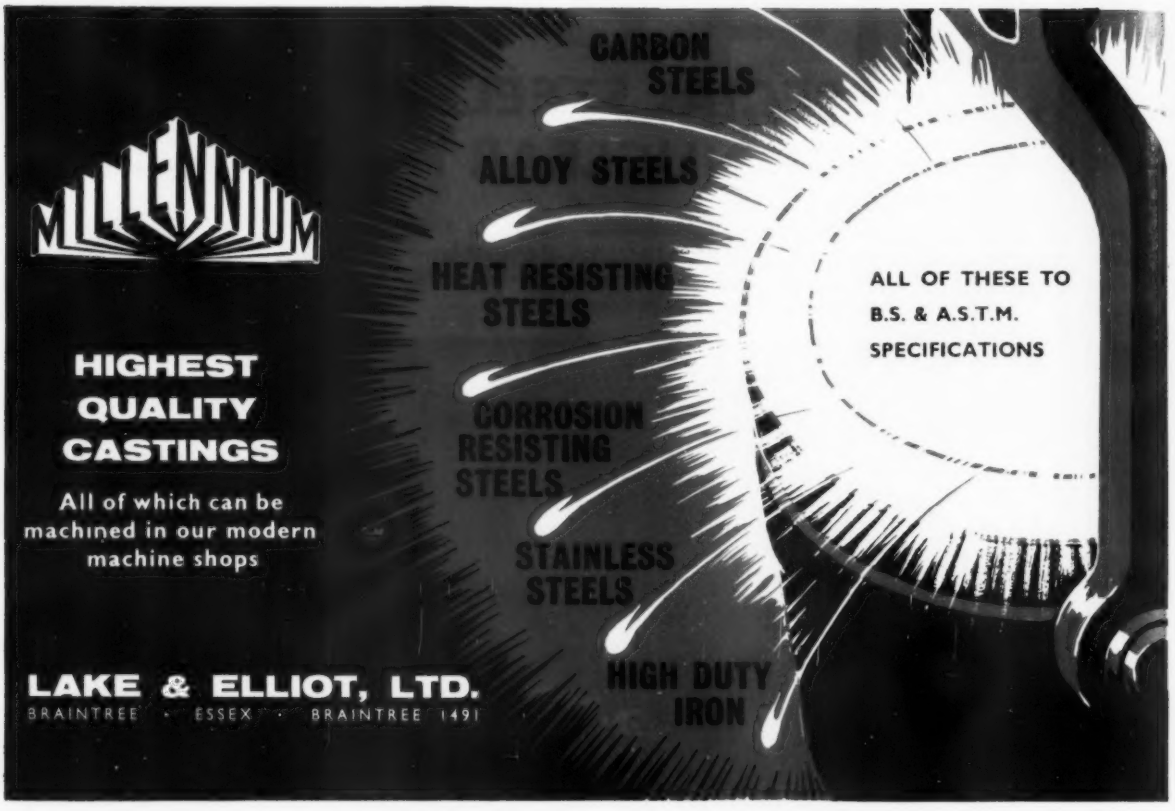
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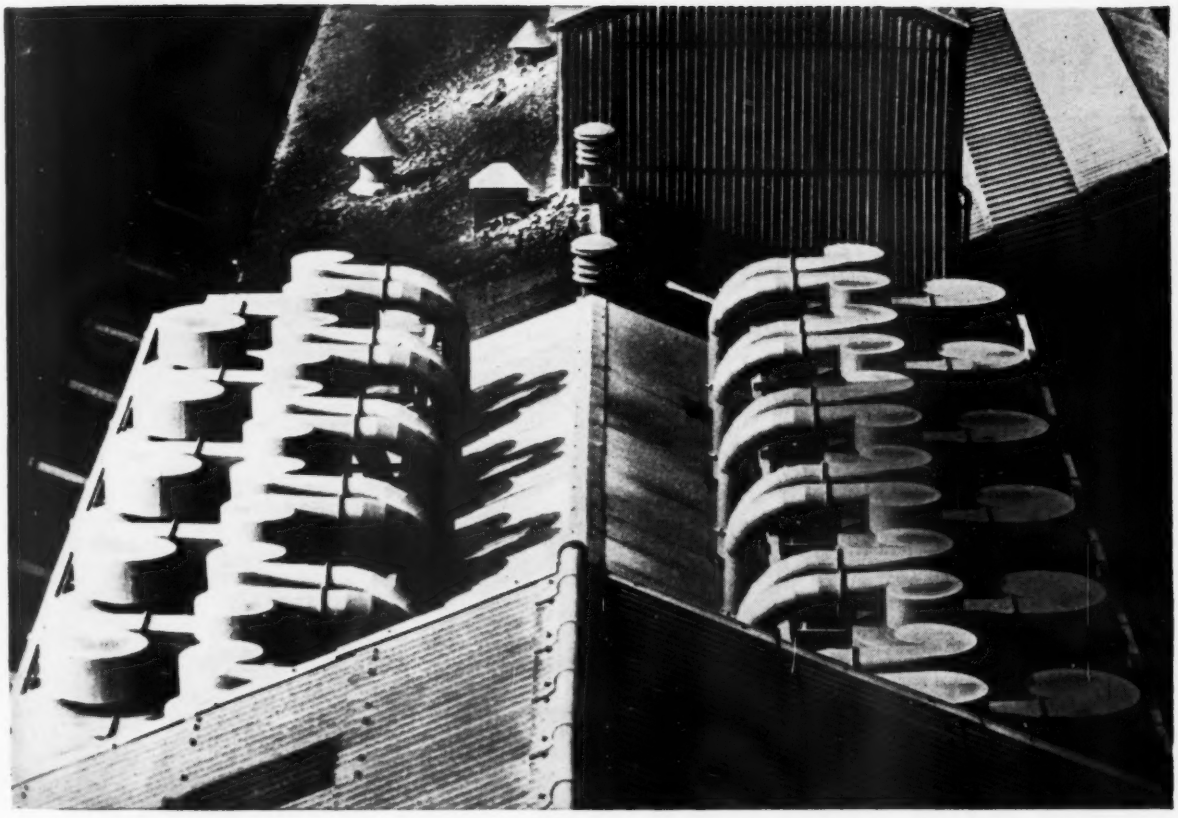

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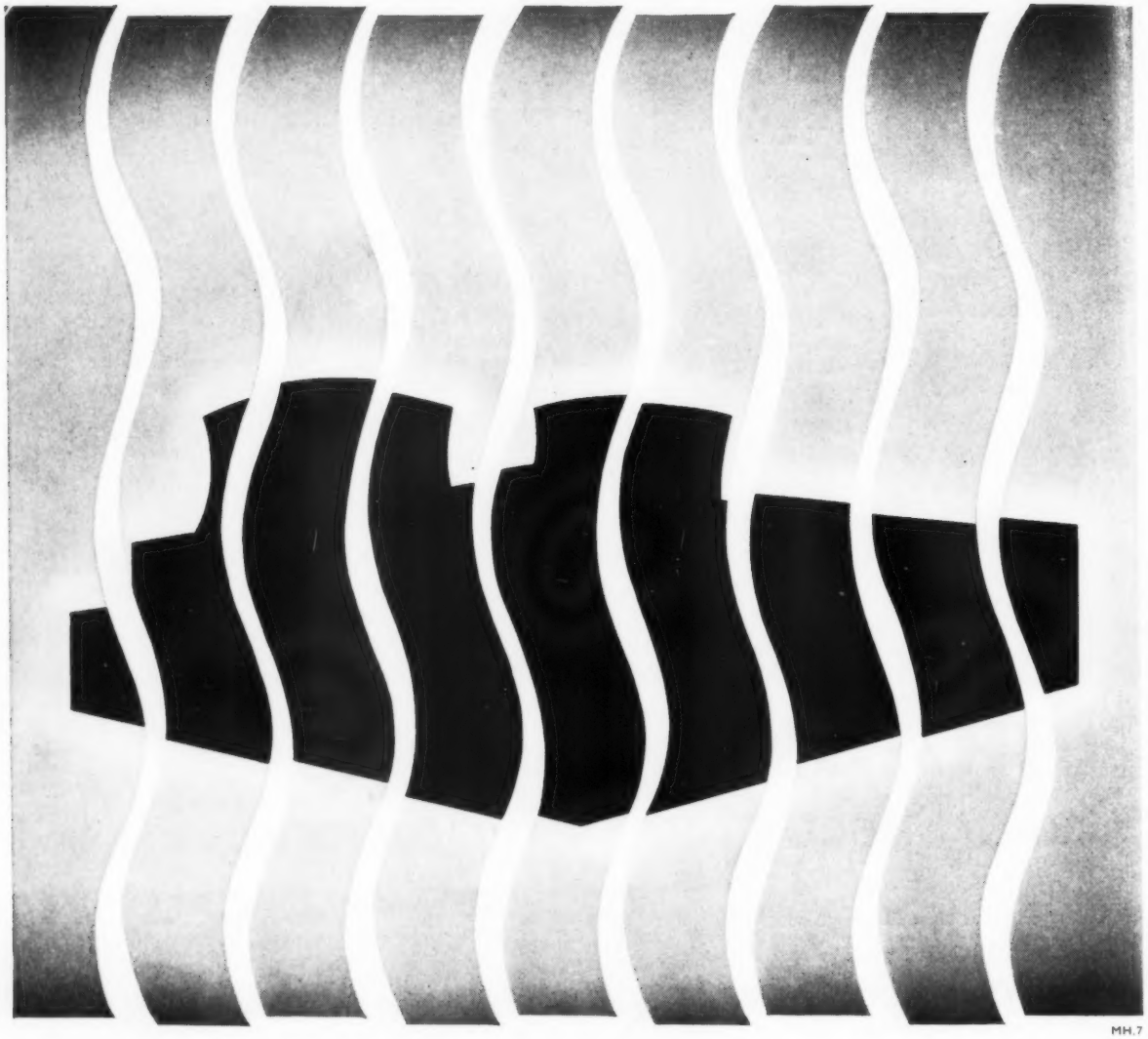

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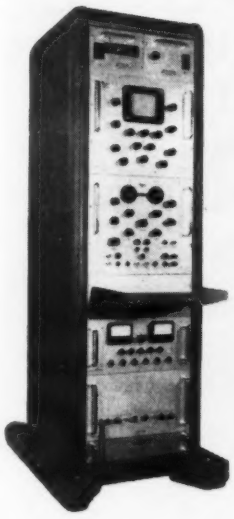

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Publishers Column

The real thing

One of the biggest problems in the rapid development of nuclear energy for peaceful purposes is the straightforward one of training enough people—from the top-flight scientist to the laboratory technician or power plant shift engineer. Lectures and reading can do a lot but there comes a time when practical experience is essential and for this real neutrons and real gamma radiation are necessary. The cheapest, simplest and safest way of doing this is undoubtedly by a low power training reactor and of these there are now quite a number available—offering a wide variety of facilities.

We therefore thought we would be doing a useful job if we summarized these in a convenient form so that educational and other authorities could obtain, as it were, a bird's-eye view of the types available. The Editor and his staff have spent several months compiling this feature and have been in constant touch with all the appropriate companies. We would like here to acknowledge the unfailing help they have given us. The information is of necessity very much abridged but we hope that those whose interest has been stimulated will write off to the companies for further details than we have been able to present.

Our front cover choice was of course dictated for us by the nature of the principal article in the issue but our problem was to convey the idea of the feature without portraying any particular reactor, which would have been fine for the company whose product it was but not so for the others. So to be scrupulously fair we decided to do an entirely mythical reactor suggesting merely a theme. Any resemblance to a real reactor must lie in the eye of the beholder. The Editor says it would never work: the Art Department say it is a satisfying design. Us? We like it.

a vital role at Hinkley Point

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Bradwell
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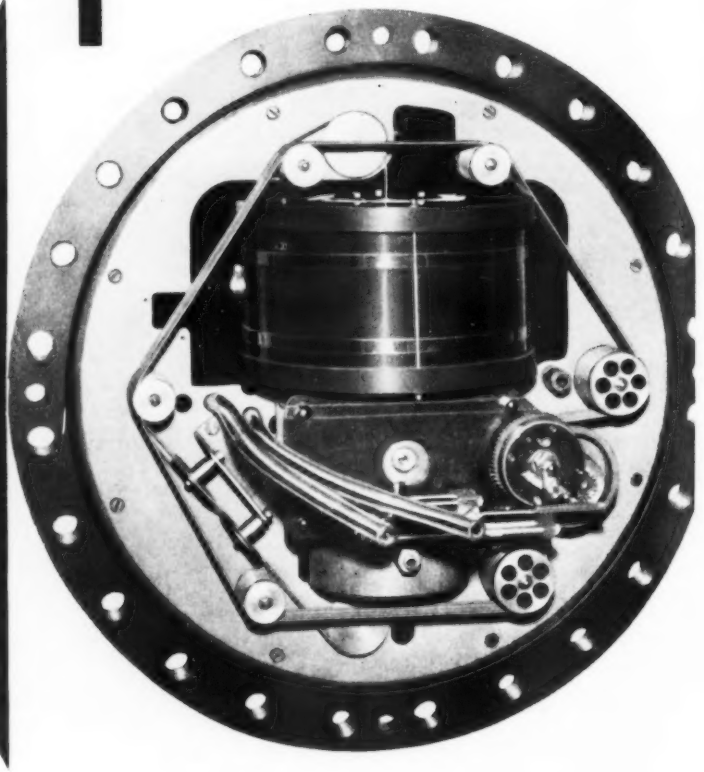

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A pat for advertisers

SIR: Allow me to congratulate you on your bold move in removing advertisements from the front cover of your journal. I am certainly not opposed to advertising and in fact I find some advertisements more interesting than some of the editorial, but I do think that the first glimpse one has of a magazine should be of editorial. After all, in daily newspapers—with one notable exception—the first page now belongs to the editor and it is good to see this tendency spreading to the technical Press.

I notice also that the standard of advertising has greatly improved recently in that more and more firms are giving technical details of their products or really concrete news of their activities. This I feel sure is what the engineer wants—not just vague claims about what the firm could do if asked.

Skipton, Yorks G. R. BROWN

▶ *The improvement Mr Brown speaks of is, of course, in large part due to the fact that more and more firms are now actually in nuclear business and so they have plenty to say. In all fairness, however, we should point out that* NP *is not only read by engineers and many advertisements are directed towards management and planning interests.* *Ed.*

Control for reactors

SIR: Whilst Dr Wootton's article (NUCLEAR POWER, February) indicates the detailed critical appraisal which is given to structural and mechanical features when designing a reactor from first (or rather 'Calder Hall') principles, the apparently cursory treatment of control problems leaves the reader with the impression that little remains to be established in a new design but the required number of control rods, and presupposes that control of the reactor by variable blower speed and a healthy negative temperature coefficient is the final answer.

This seems to be at variance with his claim not to be wedded to the engineering principles used in the Calder plant.

Again, no mention is made of instrumentation involved in the new design. No doubt with nuclear base-load stations at their present stage much instrumentation is needed, with every indication that for the immediate future still more may be required. In the long term, however, it will be necessary to design plants in which this can be drastically, though safely, reduced. Automatic control of the plant is obviously desirable, both to safeguard the reactor from unnecessary temperature gradient stresses and to relieve the monotony of an otherwise tedious task.

The instrumentation and control system (as opposed to control mechanism) design has a direct bearing on the safety of the reactor, the cost to the customer, and the design of the rest of the reactor (pressure vessel entries, accessibility for maintenance, etc,) and surely therefore deserves mention in choosing and optimizing reactor parameters. It is unfortunately often all too convenient to leave the control engineer the job of fitting in the necessary control system as best he may, after conflicting requirements of other

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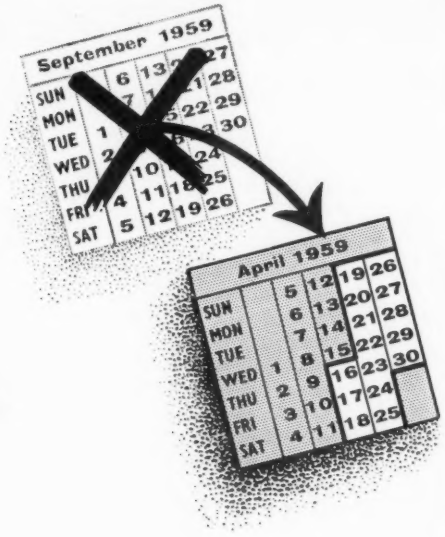

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SIR!

continued from p. 75

aspects of the design (fuel, fuel handling, blowers, etc) have been resolved.

Sperry Gyroscope Co Ltd J. WALKER
Stonehouse, Glos.

▶ Dr Wootton replies—

'Mr Walker's comment that my article gives rather cursory treatment of control and instrumentation problems is justified. He will, however, recognize the difficulty of dealing adequately with the very many interrelated aspects of nuclear power station design. If the article was to be kept of a reasonable length it was unfortunately necessary to ignore a number of most important factors when discussing the derivation of the design parameters.

A new station of the type being discussed would probably include for frequency governing of the turbo-alternators and integrated automatic control system for the reactor.' *Ed.*

Misleading

SIR: In your article *British coffins may sell abroad* (*Industrial Newsdesk, February*), you print a photograph showing one of the 2-ton lead coffins being used at present with the exponential experiment at Imperial College. This coffin was designed and specified in detail by the Nuclear Power Group at Imperial College, and manufactured by Westover. It is perhaps misleading, therefore, to state that these containers were 'originally developed by Westover & Co Ltd for Harwell and Imperial College.'

Lecturer in Nuclear Power R. E. STRICKLAND
Imperial College, London

Refreshing

SIR: I have only just seen K. L. Stretch's article in your December, 1958, issue and I must say that it was refreshing to read a really original view of the vexed question of nuclear power economics as applied to Britain. I would certainly not go all the way with Stretch but I am getting a little tired of the uniform views regularly presented by a variety of more or less official spokesmen.

Given that nuclear capital costs can be cut quite appreciably by scale effects and that conventional capital costs are susceptible only to marginal improvements, the question really devolves on fuel charges. Specifically, how much is coal going up and how cheap can nuclear fuel be made? Stretch is in a good position to know, as far as anyone can, the answer to the first part of the question, but I doubt if his figures on nuclear fuel replacement (table IV) are at all realistic. Hinton sees the fuel replacement charge in pence per kWh sent out falling from 0·24 in 1960 to 0·06 in 1990 whereas Stretch keeps the figure at 0·24 for the whole 30 years. Obviously, as temperatures go up, element costs *per se* will go up, but with the increased burnup and thermal rating expected, the specific cost must come down. What the exact figure will be no one can really say at this stage, but I'd have thought if the fuel costs cannot be brought down in 30 years, the nuclear technologists will have failed in their task.

Sydney, NSW PATRICK STONE

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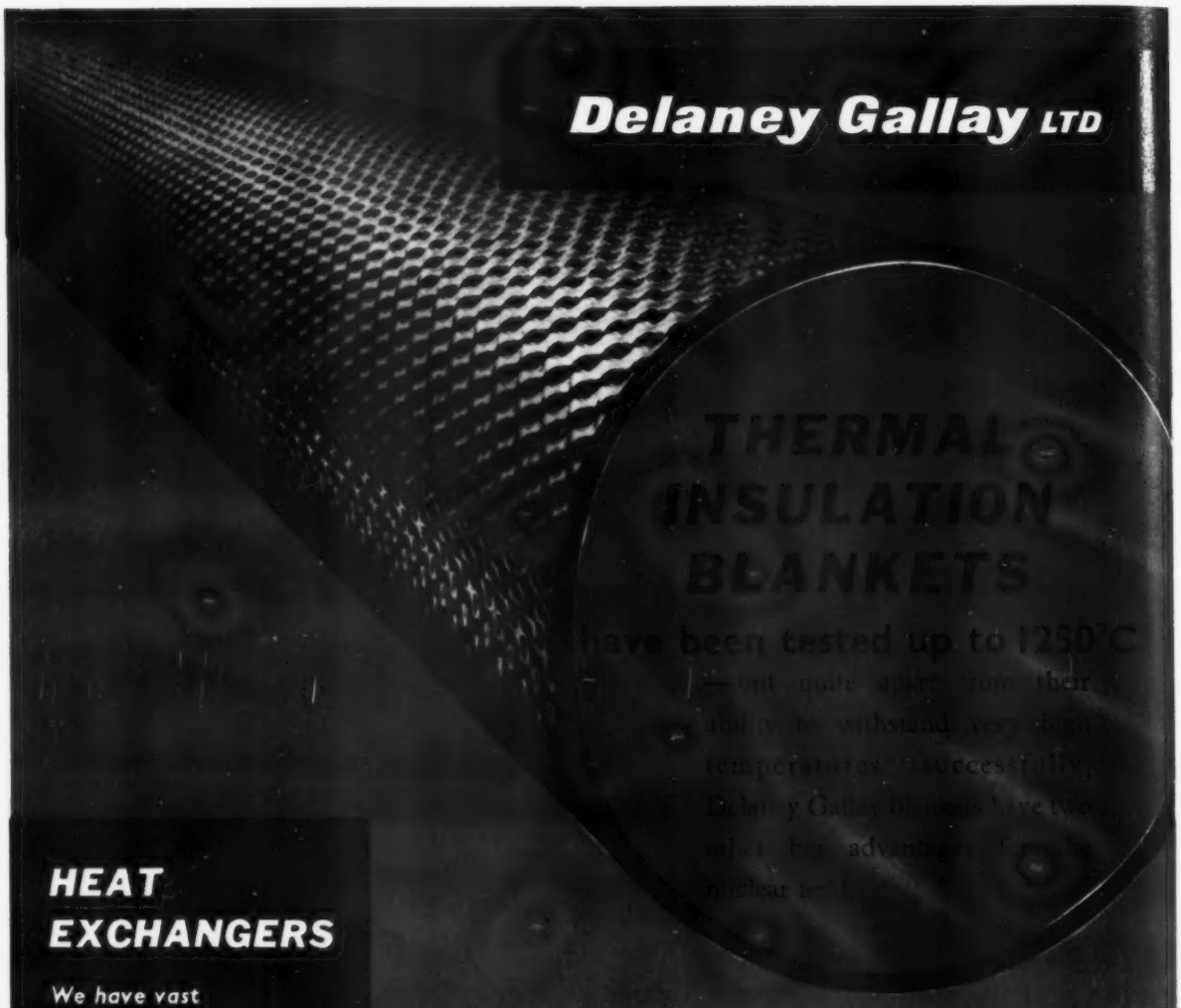

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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
MARCH 1959 VOLUME 4 NUMBER 35

Latching back the door

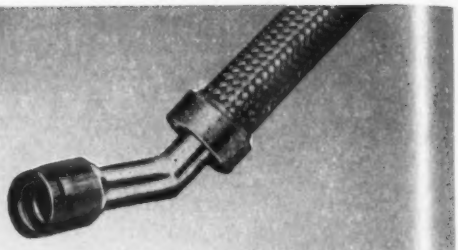
Any hopes industry might have had that the UK-Euratom treaty would somehow automatically lead to orders were well and truly dashed when, to a lavish accompaniment of rams' horns, the long-awaited agreement was unveiled on February 4. As we foreshadowed some months ago there is no intention to set up a joint research organization or permanent delegation to Euratom, no target for reactor construction and no financial assistance whatsoever. Compared therefore with the US-Euratom agreement, which has all these things on a lavish scale, it comes, if not as a surprise, still as a keen disappointment.

Of the treaty's 19 articles only a few are of much practical importance, clauses such as those covering exchanges of unclassified information and provision of educational facilities hardly warranting the dignity of a diplomatic treaty. The most important are those covering fuel supplies and European utilities now have the assurance that if they buy a British reactor there will be fuel to go with it, together with reprocessing and plutonium buy-back. This situation of course already existed in Italy, which has had a power bilaterial for over a year now. The agreement conveniently extends this to the other Euratom countries. Thus British firms will now be able to go out and sell with added confidence but it will still be on the traditional firm-to-firm basis with Euratom as a referee.

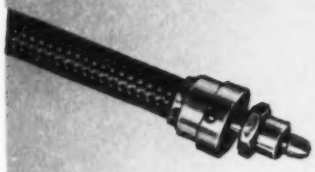
The Wise Men's suggestion of 15,000 MW by 1967 has of course long been abandoned and no firm target has yet been announced by the Community. It is believed however that the Commission now has a figure in mind of about 4000 MW by 1965 of which 1000 MW will probably be met by American-type reactors, leaving 3000 MW still uncommitted. Taking into account the quite considerable nuclear productive capacity in France and the potentially even greater output in Germany there would however remain quite a considerable slice of reactor construction that could come our way if we play our hand correctly.

The UK-Euratom agreement will undoubtedly go some way to help, since it indicates that we are now officially approved. But until its scope is widened to include more positive features of cooperation at all levels—Government, Authority and Industry—we shall continue to play the poor relation. As a start the Government should consider seriously whether it has not made a bad mistake in not having a permanent British delegation at Euratom HQ. This has been excused because we are relatively close geographically but, as things are at the moment, if a quick answer were needed by Euratom there is no doubt who would be asked.

British industry has poured a vast amount of money into nuclear development in the last few years and it is about time it had some return. The Euratom agreement has not opened any doors that were not open before but perhaps it has latched them back so that they won't slam shut without warning.



Nucleonics and Plessiflex



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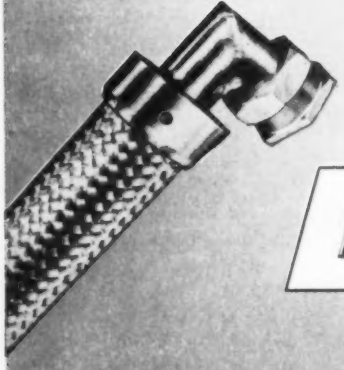

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Worldview

the month in atomic energy

GEC land Jap contract

Japan's first nuclear power station is to be built by the General Electric Co of England. Announcing this in London on Feb 24, GEC director Arnold Lindley said it would be worth about £M30 and it was hoped to finalize contract details later this year.

The station, with an output of 150 MWe, will be powered by a single gas-cooled graphite-moderated reactor with four boilers. Unlike Hunterston, on-load fuelling will be from above—an earthquake feature.

Pact offers UK opportunity

The Agreement for cooperation on the peaceful uses of atomic energy between the United Kingdom and the European Atomic Energy Community (Euratom) was signed in London on February 4.

Under nineteen articles the agreement, concluded in the first instance for ten years, provides:

Exchanges of classified information, commercial information and patent rights (on terms); scientists and technicians; and educational facilities.

Assistance in procurement, or help in design construction and operation of reactors (on terms); fuel manufacturing and reprocessing plant; materials, equipment and 'other requirements.'

THE AGREEMENT is signed by the Rt Hon Selwyn Lloyd (left) for the UK and Dr E. Medi of Italy for Euratom. Dr Medi was accompanied by Dr Krekeler of Germany, Paul Hubert de Groote of Belgium and Emmanuel Sassen of Holland, all Euratom Commissioners

Supply fuel for UK-designed reactors and possibly others; reprocessing of fuel in the UK; buy-back by the UK, if required, of any special materials (e.g. Pu or U-233) produced from UK-supplied fuel. A guarantee is written in that terms for these deals will not be harder than those for the most favoured customer outside the UK.

Security for peaceful uses only; a safeguard and control system is to be set up. The International Atomic Energy and the European Nuclear Energy agencies are to be brought in if necesary.

Insurance to secure protection against third-party liability on a cooperative basis.

Bilaterals to be renegotiated for Euratom to take over rights and obligations of existing agreements.

Implementation will be effected by representatives meeting from time to time to consult at the request of the other side. At first there will be a technical standing committee—later there might be a supervisory body at ministerial level.

Subsequent to the signing of the agreement, Heinz Krekeler, another Euratom Commissioner, said that although unlike the Euratom-US agreement no finance or reactor projects had been included UK manufacturers would now be in a position to compete in a market requiring at a conservative estimate 4000 MW of nuclear power installations in the next six years for the Euratom countries.

During the three day visit of the Euratom Commissioners they were received by the Prime Minister, members of the Government and the UKAEA and despite this tight programme visited the Berkeley site.

Knights move

The first Master of Churchill College at Cambridge will be Sir John Cockcroft and when he takes up this appointment later in the year he will cease to be a full time member of the AEA. Sir William Penney who has been combining the two posts of Member for Weapons and Director of the Weapons Group will now replace Sir John Cockcroft as Member for Research.

Dr Nyman Levin, Deputy Director of AEA's Weapon Group at Aldermaston since last July is to succeed Sir William Penney as Director. During the war Dr Levin was seconded to the Admiralty and was responsible for the establishment of cross-channel VHF links used during the invasion of Europe. Before going to AWRE he was Chief of Research and Development at the Rank Precision Industries group.

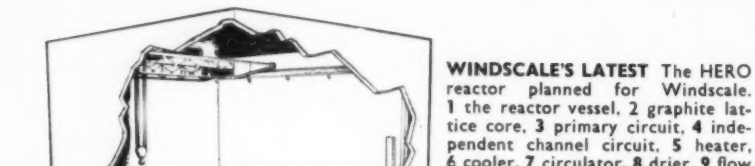
The Deputy Director will now be Mr E. F. Newley who, since 1957, has been Chief of Warhead Development at Aldermaston.

Successor for Strath

The Prime Minister has appointed Sir Alan Hitchman KCB, Permanent Secretary of the Ministry of Agriculture, Fisheries and Food, to succeed Mr W. Strath CB, as a full-time Member of the UKAEA. Sir Alan Hitchman, whose appointment becomes effective from April 1, 1959, will have special responsibility for the external relations and commercial policy of the Authority. Mr Strath takes over duties as Permanent Secretary at the Ministry of Supply.

SIR ALAN HITCHMAN
. . . fresh fields

In earlier appointments Sir Alan has been in close contact with the engineering industries as from 1941 until the end of the war he was principal assistant secretary in the Labour Supply Department and, under the Director-General of Manpower, was in charge of the supply of labour for the iron and steel, chemicals, engineering and munitions industries. He became Deputy to the Chief Planning Officer and was appointed a Third Secretary in the Treasury in 1948. When the Government established a Ministry of Materials in 1951, Sir Alan was appointed Permanent Secretary to bring the new Ministry into being by transfer and amalgamation of staffs. Doubtless now the Euratom-UK Agreement has been signed Sir Alan Hitchman



WINDSCALE'S LATEST The HERO reactor planned for Windscale. **1** the reactor vessel, **2** graphite lattice core, **3** primary circuit, **4** independent channel circuit, **5** heater, **6** cooler, **7** circulator, **8** drier, **9** flow control valve and **10** control room

will be devoting considerable time and effort boosting the Authority's services and materials in Europe.

Second thoughts on CTR move

The AEA are reconsidering their decision to move the Controlled Thermonuclear Reactor project to Winfrith Heath. It is felt by the research staff that it would be preferable to locate the site nearer to Harwell because of the close liaison which will have to be maintained between the two establishments. Culham Airfield near Abingdon has been mentioned as a possible location. Any decision made on this matter will not in any way effect the build-up of Winfrith Heath where work is proceeding on plant for fission reactor development.

Windscale gets another reactor

To accelerate the development of gas-cooled reactors a new research reactor, the Hot Experimental Reactor of 0 (zero) power, HERO is to be built at Windscale. Its function will be to complement the work of the Advanced Gas-cooled Reactor, AGR, at present under construction and near which it will be sited. Low radiation level measurements and several alternative fuel arrangement experiments will be carried out in it after completion early in 1961 at an estimated cost of £M1¼.

HERO, which will generate a few kilowatts of heat, will consist initially of a graphite structure some 19 ft in diameter and height incorporating the important feature that it will be possible to dismantle it and rebuild it in a variety of ways. While like the AGR as regards its clusters of pencil-like rods of uranium oxide sealed in beryllium cans arranged in channels in the graphite on a regular lattice HERO will, in fact, operate in exactly the reverse to AGR in that high temperature carbon dioxide will be pumped into the graphite core. This reactor will enable sensitive techniques necessitating low radiation level measurements to be carried out so that extremely careful optimization of reactor cores may be assessed. In addition, stability and control of the AGR fuel will be studied all of which is aimed at improving the efficiency of gas-cooled reactors for the nuclear power programme.

GERMANY

OMR chosen for first ship

The executive company Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt mbH (GKSS) has placed a development contract with Interatom for a nuclear power reactor for the propulsion of tankers up to 40,000 deadweight tons. GKSS is a company consisting of representatives of the Land Governments, industry and science which has started practical work on the nuclear-powered ship at Hamburg. Interatom, formed by Atomics International and Demag and operating at Bensberg will be responsible for the organic moderated reactor OMR for the project. This type of unit has been chosen on the grounds of its potential economy, ease of operation, inherent safety and has the added advantages of being available on a comparatively short delivery with the use of normal engineering materials in its construction. While it has not yet been decided whether this reactor will first be erected on land to gain operating experience or installed directly into the ship, the design is suitable for 10,000 shaft horsepower and it is anticipated that the vessel will be ready for its sea trials by the end of 1963 or early 1964. Applying this type and size of nuclear power unit to a 38,000 dwt tanker the cost rises from $M10·57 to $M14·2, without taking into account any development charges.

UK success at Hamburg

Deutsches Elektronen - Synchrotron (DESY) research group Hamburg, have ordered a 40 million electron-volt Electron Linear Accelerator from Metropolitan-Vickers Electrical Co Ltd. This order, valued at approximately £250,000 was secured against world competition. The equipment has an overall length of some 10 metres and comprises five sections of accelerating waveguide, each 1½ metres long, together with an electron gun and pre-buncher at the injector end. Each accelerator will be fed by a high power klystron. The accelerators will inject a beam of 40 MeV electrons into a large electron synchrotron which will then further accelerate the electrons to an energy of 6000 MeV. This second stage acceleration is made possible by rigorous restrictions on the output of the linear accelerator used, which is of the travelling wave type energized by short wavelength radio-frequency power. Very little variation is permissible on the specified 40 MeV energy and the electron beam must be compact, small in diameter and with very little divergence. The output at this level is in the form of short pulses of current of 2 microseconds duration, repeating 50 times per second. Each pulse of current must sup-

175 MW. At the USAEC's test site in Idaho the big ETR delivers full power. First ever taken of a reactor this size, the picture was taken through 2½ in. glass and 22 ft water. 1/25 at f : 16. Pan-x. Sole illumination, Cerenkov glow

ply 125 milliamps within the strict limit of energy and beam geometry imposed by the acceptance requirements of the synchrotron.

Krupps to build reactor

A 15 MW experimental reactor has been ordered from the Krupp-Brown Boveri group by a North Rhine Westphalia organization of power companies. This reactor is of the gas-cooled type utilizing spherical graphite fuel elements. The design was started some twelve months ago when the companies Fried. Krupp of Essen and Brown Boveri und Cie A.G. of Mannheim were awarded a development contract and under Dr. R. Schulten, Brown Boveri have developed the pebble-bed type of reactor in which the maximum gas operating temperature will be in the region of 1100°C. This project will be used to investigate problems concerned with large nuclear power reactors and to develop a 100 MW plant of the same type.

JAPAN

More money needed

Although the Japanese Government spent nearly £9 million on atomic energy projects in the last financial year Japan's Atomic Energy Commission needs more money and more research. The research institute at Tokai-Mura is expanding and an interim uranium refining plant is now under construction there. This lack of funds is reflected in the protracted negotiations with the three UK consortia for the nuclear power station project and the Japanese are trying to find ways and means of reducing the overall cost of the project by at least £1 million.

SCANDINAVIA

Scanatom proposed

At a meeting of the Industrial Federation Professor E. Laurila, leader of the technical physics laboratories in Helsinki proposed that the Scandinavian countries came to a similar arrangement for atomic matters as Euratom and that cooperative agreements were made. Such proposals would greatly increase the existing interchange of technical and scientific information between Denmark, Norway and Sweden and would provide a sounder economic basis especially for such major projects as nuclear propulsion for ships and fuel processing plants.

SPAIN

Funds made available

The Spanish Junta de Energia Nuclear will participate in the European Company for the Chemical Processing of Irradiated Fuels (Eurochemic) and will contribute the equivalent of $M1·5 to Eurochemic's capital. OEEC approval was given when Spain agreed to adhere to the OEEC Security Convention of December 1957, which prevents jointly developed nuclear facilities from being used for military purposes. The plant, the first jointly owned, will be built as part of the OEEC's European Nuclear Agency's programme and will act as a pilot undertaking for the building of the much larger installations which will be required as the nuclear power programme expands.

SWEDEN

Power bids invited

A British firm of consulting engineers, Kennedy and Donkin of London, have been selected by Kungliga Vattenfallsstyrelsen (State Power Board) to evaluate tenders for nuclear power plant. Just back from Stockholm, Mr Geoffrey Kennedy told NUCLEAR POWER that although AB Atomenergi were currently studying heavy water-moderated power plants, the State Power Board were not convinced that costs would be competitive with foreign-designed plants and they had therefore invited international bids to a rather open specification, setting no definite output limits. The main criterion in judging tenders would therefore be that of unit costs.

A possible Swedish nuclear power requirement of about 1000 MW by 1970 is foreseen and the winning bid for this competition might well set the pattern for meeting this target. Proposals are due in by March 15 and it is hoped that the result will be known by about mid-May. No definite location has been selected for the station but bidders have been given hypothetical yet realistic site data.

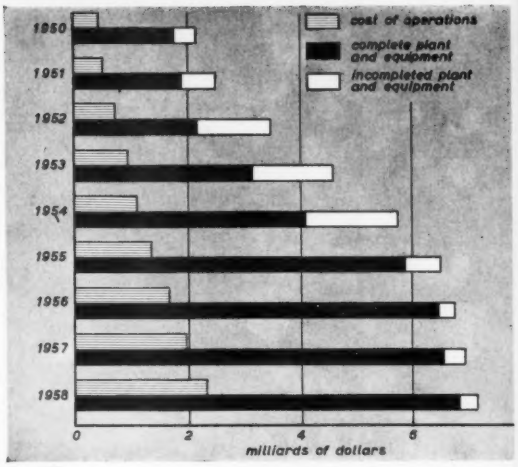
Mr Kennedy said the free specification would give the British groups a better chance than they had in the Italian SENN bidding. There, had the required output been 250 MW instead of 150 MW unit cost figures from the gas-

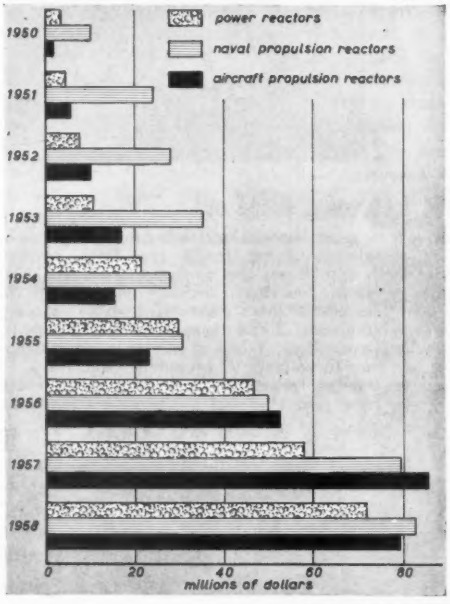
AMERICAN ACTIVITIES

The 1958 US Atomic Energy Commission's Annual Financial Report

Cost of operations and investments in plant and equipment

Despite substantial reductions in the unit cost of materials produced and lower cost of uranium concentrates, operational costs including depreciation continue to rise, reaching a peak of $2299 millions in 1958. Investment in production plants, research laboratories and other facilities owned by AEC increased during the year by $2 hundred million to $7·1 milliards.





Development and research costs. Power, naval and aircraft propulsion reactors

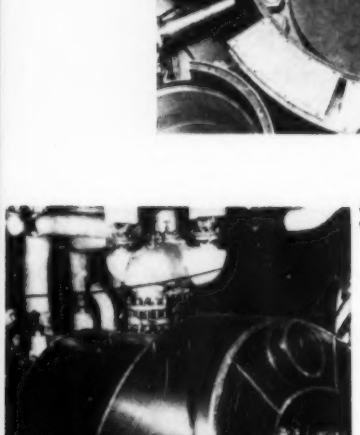
Except for the pressurized water, fast power breeder and boiling water types, increased expenditure over the previous year was incurred by all the power reactor projects. In addition work on gas-cooled and molten salt reactors was started.

The continued increase in funds directed towards aircraft propulsion reactors is of especial interest as for the last two years some 80% of the costs have been in connexion with manned aircraft units.

Apart from the expenditure shown on this chart a further $19 millions was directed to controlled thermonuclear research during 1958.

1

2



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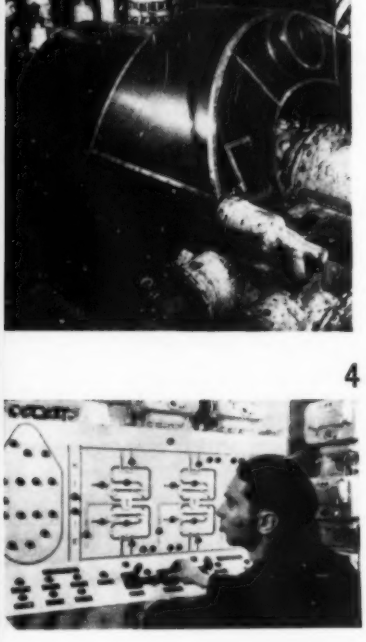
Russian icebreaker fitted out

The Soviet icebreaker 'Lenin' has started a series of trials following completion of her fitting out. Static reactor tests have been carried out and operating trials will take place during March. The basic circuitry of the plant is shown by **1** one of the three pressurized water reactors and its primary circuit, **2** the three steam generators in the reactor compartment, **3** one of the four main steam turbines of the turbo-electric propelling machinery, **4** radioactivity warning panel and **5** main control room handling the steam and electrical power generation plant



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5

cooled contenders would have been very much better.

As an alternative to this competition, the State Power Board is also asking for bids to a 100 MW specification for a direct comparison on total and unit costs with the 100 MW heavy water plant being proposed by AB Atomenergi.

– UNITED ARAB REPUBLIC –

More facilities for Middle East?

The Chairman of the IAEA Board of Governors, Ambassador Carlos Bernardos and the Director General, Mr Sterling Cole accompanied by Agency officials are visiting the United Arab Republic. The IAEA party will meet UAR Foreign Office and Atomic Energy Commission officials and visit installations in the country. This is the follow-up to the two technical exploratory missions IAEA sent last year to study the possibilities of heavy water production at Aswan, uranium extraction from phosphate ores and training facilities at the Cairo isotope centre.

——UNITED STATES——

Utility companies wooed

The Westinghouse Electric Corp proposed to the utility industry that a 330,000 kW nuclear power plant could be built, that by 1965 the plant would produce power at costs competitive with fossil fuels in the higher fuel cost areas of the US. The plant which Westinghouse have offered to develop, design and build is of an advanced pressurized water reactor type and would be the fourth generation of the pressurized water type, forming part of the company's broad, multi-front programme.

First medical TRIGA

The first specifically medical application of the TRIGA reactor is the US Veterans Administration Hospital at Omaha. This reactor is of the 10–100 kW nominal power level below-ground model and will be incorporated within a large hospital building. The programme of work is to include the production of short half-life isotopes for use in dilution and flow studies, pharmacological and toxicological research; investigation into the metabolic fate of antibiotics and 'tranquillizers' and the study of activated chemicals selectively concentrated by tissues.

Control eased

AEC have proposed amendments to the licensing regulations which will simplify the procedures relating to sealed devices containing radioisotopes employed in research and industry. The measuring and gauging equipment concerned is that of the 'light producing' and 'ionizing air' types which are constructed with built-in protective features and may be used by untrained personnel. AEC control will be maintained over the manufacturers and distributors; the user will only be able to subsequently dispose of the equipment to either the manufacturer or someone specifically licensed by the AEC. This simplification will be particularly useful for users of thickness gauges in the metal foil, paper, tobacco, and plastics industries; emergency exit markers in vehicles and buildings using radioactive isotope-operated light producing equipment and on printing presses, textile and photographic processing equipment employing air ionizing devices.

——INTERNATIONAL——

Armand steps down

Due to unfortunate continued ill health Louis Armand has been forced to resign from the Presidency of Euratom and a member of the Scientific Committee of the Commissariat à l'Energie Atomique, Etienne Hirsch, has been appointed the new president. Following research and administrative experience with the chemical company of Ethyl-Kuhlmann he was connected with armament technical work and supplies. Since 1952 he has been Director-General of the Commissariat Général du Plan. This appointment

comes at a time when projects planned by Euratom are taking shape and industry is increasingly seeking guidance and technical assistance from Euratom.

Germany sells US know-how

Degussa the large German company which since 1941 when it was the first European company to investigate uranium fuel production has been actively studying manufacturing problems of nuclear fuels. Arrangements have now been made with the US Mallinckrodt Chemical Works to act as their Continental European representative and exchange technical information on fuel element production. At the same time Degussa have entered into agreement with the Japanese Sumitomo concern to sell them the know-how for uranium production. Initially this information will only cover small-scale output but a larger continuous output will follow.

HTGR plan settled

The Winfrith Heath (UK) high temperature gas-cooled reactor project is to be developed as a three cornered UK-Euratom-ENEA affair. This was announced by the OEEC's European Nuclear Energy Agency on February 12. Known as 'Dragon' the reactor will be a graphite-moderated helium-cooled plant with about 10 MW output. Countries cooperating besides the UK and the Euratom group are Austria, Denmark, Norway, Sweden and Switzerland. The financing of the five-year programme including the cost of the reactor and facilities will be spread among the member countries. The overall cost is estimated to be some £13·6 millions of which £M10 will be provided by the members, both Euratom and the UK giving 43·4% each. The balance of £M3·6 will be met by the UK which will retain ownership of the installation on completion of the Dragon project. In the course of the next three months a joint team will be built up ready to start work.

Assessing commercial prospects

The European Nuclear Energy Agency is organizing a conference on 'Industrial Prospects in Nuclear Energy' which will take place at Stresa (Italy) from May 11 to May 14. Its aim is to bring together senior management from the OEEC member countries, US and Canada to evaluate the commercial prospects for industry which are offered by nuclear energy, the probable markets and returns for materials and equipment and the amount of investment required; the conference will cover :

economics of nuclear power ;
financing national and international programmes for the development and production of nuclear energy;
atomic law and special regulations;
management problems;
market forecasts for materials, equipment and instruments.

There will also be a visit to the Italian nuclear research centre at Ispra.

WORLDBRIEFS

● **Ghana** A UK trade and industrial mission led by Sir George Binney, DSO, is visiting Ghana. Mr Bryan Donkin will make an assessment of possible developments nuclear as well as thermal and hydroelectric power generation.

● **Portugal** Atomic engineering will be included in the British Trade Fair which is being held in Lisbon between May 29 and June 14.

● **United Kingdom** Investigations for nuclear power station sites will be carried out in two areas on the central south coast. Ground surveys, trial borings and hydrographic surveys will be made for the Central Electricity Generating Board.

● **United States** The AEC have signed a contract with Carolinas Virginia Nuclear Power Associates (CVNPA) for a demonstration heavy water moderated pressure tube-type reactor power plant at Parr, South Carolina.

● **United States** Three companies, the Ford Instrument Co division of the Sperry Rand Corp, the Isbrandsten Co, and the Maryland Shipbuilding and Drydock Co, have formed a private group to build a nuclear powered merchant ship. Estimated costs are $M5 for development and $M10 for tests and building. The group plans to have the reactor system ready for testing within the next three years and the vessel would be ready for sea trials six months later.

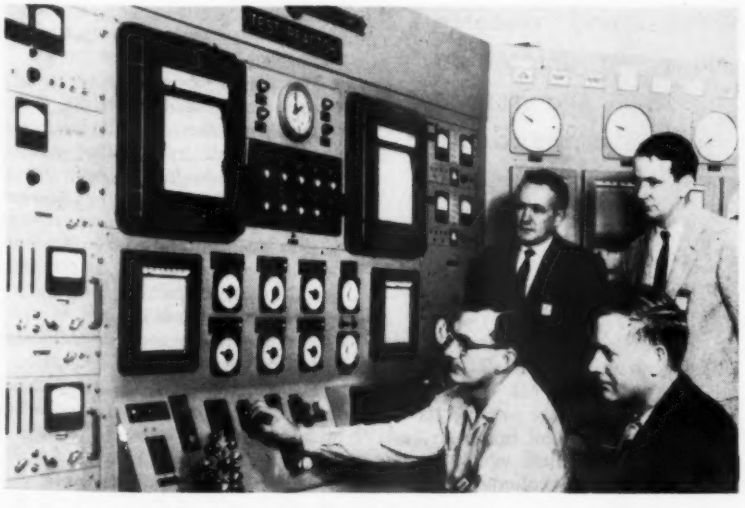
FRANCO-RUSSIAN GET TOGETHER V. S. Emelyanov (left), president of the Soviet organization of the peaceful use of the atom, talks with Pierre Couture, Jacques Soustelle and Francis Perrin during a visit of Soviet scientists to the Saclay and Marcoule atomic establishments

● **United States** The Rice Institute at Houston is to purchase an Aerojet-General Model AGN-211 reactor for use by its Abercrombie Laboratory.

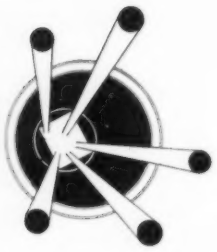
● **International** One of the first acts following the signing of the UK-Euratom pact was the presentation by AEA to Euratom of a library of British films on atomic energy.

World Reactor Catalogue

In response to numerous requests the World Reactor Catalogue published in January NUCLEAR POWER has been reprinted. Minor amendments have been included to bring it fully up to date. Copies are now available from the publishers at 2/- per copy, post free.



GENERAL ELECTRIC TEST REACTOR GOES CRITICAL At GE's Vallecitos research centre the new 30 MW reactor was notched up recently. Present were J. W. McCumsey, Paul H. Zeanah, J. O. Arterburn and operations manager H. T. Wells. It will be used for materials testing



a **Nuclear Power** special report

What's available in Laboratory Reactors

With the new low-powered reactors now on the market, universities and research organizations can achieve an integrated programme of training, research and isotope production. Here is a guide to the dozen different designs available commercially

TRIGA | *General Atomics*

Designed not only for reactor training and general research purposes, but also for isotope production on a considerable scale, General Atomics' TRIGA reactor exists in two forms differing only in the experimental facilities. In the Mk I version—that seen at Geneva—the core is at the bottom of a cylindrical tank set into the ground and therefore has no horizontal beam tubes. The Mk II model has exactly the same core but the tank is entirely above ground inside an octagonal biological shield which enables a graphite thermal column and three horizontal beam tubes to be provided.

Using only natural circulation in the pool for cooling, the continuous power rating is 10 kW but a forced cooling system can be supplied which allows 30 kW. At 10 kW the average flux is about $1{\cdot}6 \times 10^{11}$ rising to 4×10^{11} at the centre thimble. Estimated core lifetime at this rating is 10 years, 24 hours a day.

The main isotope facility is an annular magazine surrounding the core and containing 40 chambers for specimens. These are loaded through a vertical tube and the magazine is rotated by a simple handgear operating through another vertical tube, so that any particular specimen can be located. There is also a pneumatic rabbit tube permitting the preparation of very short-lived isotopes.

The TRIGA can produce an equilibrium activity of about 80 curies. For most applications however it is the specific activity that matters and, taking a minimum useful figure for tracer work of 0·1 microcuries per milligram, the machine can produce isotopes of 62 of the first 83 elements in useful quantities and in specific activity exceeding this value. For higher specific activity, the central thimble is, of course, available in a flux of from 2 to 4×10^{11} at 10 kW.

Applications foreseen for TRIGA isotopes include trace determination by activation analysis, autoradiography, tracer work in medicine, biology and chemistry. It is also suitable for bulk irradiation since quite a lot of space is available in high-flux areas near the core without adversely affecting reactivity.

For training in reactor operation, the machine, of course, has all the essential features of a power reactor, and experiments such as measurements of migration areas, absorption cross-sections and void coefficients can be readily carried out. The centre thimble can be used for pile-oscillator or danger coefficient experiments.

The above-ground version in addition to these facilities has a 4 ft x 4 ft graphite thermal column shielded on the outside by a rolling concrete plug. This provides a supply of well thermalized neutrons for experiments such as exponential assemblies. Two of the beam tubes pierce the shield radially to look directly at the core: the third is tangential to avoid excessive gamma streaming. These facilities are suitable for use in neutron spectrometry experiments.

The reactor is based on a unique solid homogeneous element combining both fuel and moderator. This is a 1·42 in. dia, 14 in. long rod of hydrided uranium/zirconium alloy containing 8 wt% of 20% enriched uranium and 1 wt% hydrogen. The rods, surmounted top and bottom by samarium poison disks and graphite

rods acting as end reflectors, are canned in aluminium and arranged, together with a number of graphite dummy elements, in grid plates. The reflector is an annular ring of graphite canned in aluminium.

Inherent safety is claimed because of a relatively large temperature coefficient of reactivity arising from the element design. If the fuel temperature rises, that of the moderator follows without delay and the average energy of the thermalized neutrons increases. The fission cross-section for these neutrons is reduced and so the reactivity is immediately reduced. In addition the U-238 resonances are broadened by the Doppler effect which again reduces reactivity. The core plates have 83 positions filled by either real or dummy graphite elements.

Control is by three boron carbide rods operating in perforated guide tubes. The rods are cable driven with an electromagnet connexion at the lower end which can be de-energized in an emergency.

TRIGA I is economical in floor space but is of course limited in its experimental facilities. The above ground model by nature of the biological shield is naturally more expensive but the increased flexibility makes it very attractive in situations where many different scientists are able to benefit by it.

10 kW TANK | *AMF Atomics*

Similar to the thirteen high-powered pools by AMF now either in operation or under construction, this training model has a design power of 10 kW. The rectangular pool is 4 ft × 4 ft 4 in. by 20 ft high, providing 16 ft of water above the core for shielding. One side there is a niche about 15 in. wide by 18 in. extending the whole depth of the pool completely unobstructed for bulk shielding studies and storing radioactive materials. Bottom and sides are lined with ½ in. aluminium plate, and the lower portion of the biological shield is of barytes and the upper of regular concrete.

MTR-type fuel assemblies are mounted in an aluminium grid plate with a 5 × 6 rectangular lattice. Three of the elements contain only half the standard U-235 content and have a central guide channel to take control rods. The 30 holes of the grid plate also take graphite reflector elements, test sample containers, etc. On three sides the core is reflected by graphite sealed in an aluminium can.

Four 6-inch beam tubes are included in the design. These terminate in

Their value in training

One of the essential features of all these types of reactor is their inherent safety. This, of course, is a most necessary requirement for any reactor which is to be used for training and teaching purposes. It must be capable of being operated and handled by inexperienced people and yet at the same time must be flexible in design and simple in construction so that the maximum possible use can be made of it. In this it then compares favourably with more conventional equipment. In addition, such a reactor must be relatively cheap to buy and operate otherwise it will be beyond the means of most teaching institutions.

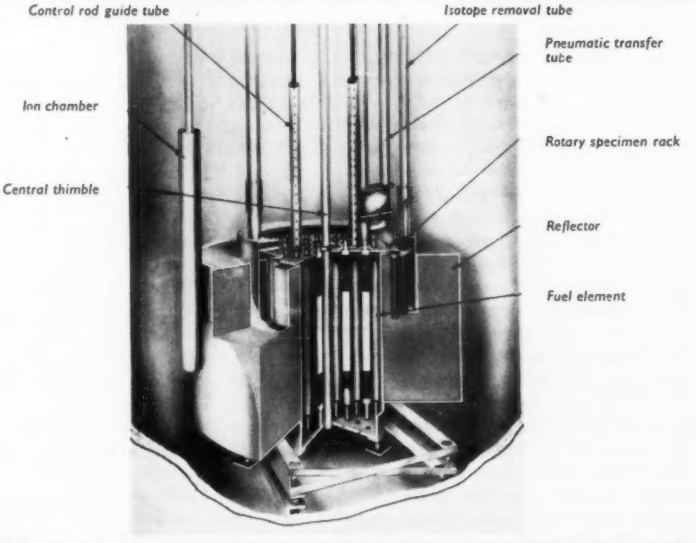
The real value of a reactor which can be used for teaching, training and research purposes will be determined by the organization which is going to use it. To obtain the widest possible use, which really means the most economic use, the organization must have a very wide variety of interests. The use of these reactors ranges over the fields of reactor physics, reactor engineering, reactor operation, health physics, the production of radioisotopes, and medical and biological studies. So a reactor put to all these uses will be much more economic than if, for example, it is only used for training engineers and physicists. This, of course, is not to say that the reactor is not capable of being used full time for such a purpose, but that the time allocated for the use of a reactor in, say, a training course for engineers and physicists is necessarily limited.

As opposed to most other types of experimental equipment, a reactor, however simple it is to construct and operate, needs its own full time operational and maintenance staff. This adds to the cost of the already expensive reactor and so makes it necessary to use the reactor for as large a fraction of each day as possible, which again means that it must have a very wide usage.

It is possible to make some comparison of the cost of this type of reactor with the cost of some pieces of equipment which will serve some of the purposes of a reactor. The only British firm in the business markets its model at £50,000 without fuel, and American prices vary from $100,000 to $250,000. As the fuel would be almost certainly highly enriched uranium, the cost of this is impossible to estimate and would presumably be a loan charge.

Alternatives and costs

A typical substitute for some of the experiments which can be performed with the use of a reactor is an exponential experiment—one, for example, is in use at Imperial College, London. This may take the form of an arrangement of graphite and natural uranium as in a reactor. Its main purpose is to predict the critical size of a reactor of the same arrangement, but in addition other measurements can be made. These are largely confined, though, to measurements of the neutron flux either on the small scale—that is across the uranium with its associated



TRIGA can be bought in either the original below-ground version, shown at Geneva and illustrated here, or above ground with a biological shield. Mk II has a thermal column in addition to these facilities

Their value in training

amount of graphite—or across the stack as a whole. Measurements of critical size can, of course, be made with a reactor, and if the reactor is suitably designed, the critical size for a large number of different arrangements can readily be determined. With this type of exponential stack, this is possible only for a small number of variations and only then after the whole stack, which is of the order of an 8 foot cube in size, has been taken down and reassembled. Also, flux distributions can be readily determined in a reactor. As an alternative, then, the exponential experiment is a poor substitute for a reactor.

The cost of an exponential stack lies largely in the graphite and uranium, but there are additional costs for such items as neutron sources, coffins for the sources and a strong and accurately level floor for the stack to stand on. About 25 tons of graphite will be contained in the stack and at, say £400 per ton, the cost will be £10,000. About 3 tons of natural uranium is also required, which again will presumably bear a hire charge. The point to bear in mind here is that an exponential experiment can only replace a very small fraction of the use of a reactor at an appreciable fraction of the cost.

As an additional example, the use of a reactor simulator can be cited. This is a piece of equipment which simulates electronically the power response of a reactor as a function of time, consequent upon changes in the reactor. It is a particularly useful training tool in the absence of a reactor, but even a very simple version will cost in the region of £5000.

No real substitute

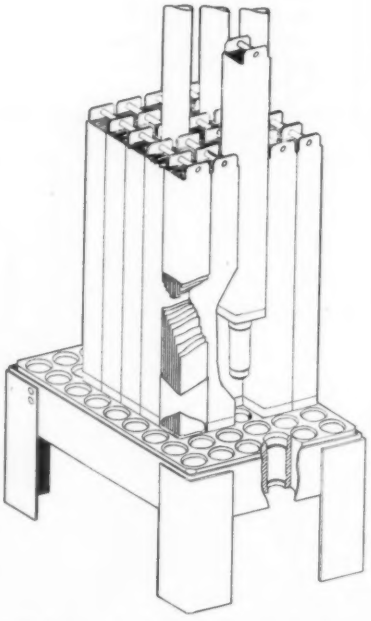
Thus replacing a reactor by even a very few pieces of equipment which will only perform a small, and at the same time very specialized, fraction of the functions of the reactor, can lead to an expenditure which is an appreciable cost of a reactor. In other words, setting up a nuclear engineering laboratory without a reactor is an expensive matter, and such a laboratory can at best only supply a small fraction of the experiments which can be performed if a reactor is available. The absence of a reactor means, in addition, that a large number of experiments cannot be performed at all. It is particularly interesting to note in view of this, however, that at the present time there is no reactor in this country in anything like full time use for educational and training purposes, but that in the USA there are already some 20 to 30 either in use or under construction.

the graphite reflector which means that the inner face is located at the point in the graphite where the flux is maximum, that the inner 11 in. of the tubes are surrounded by the reflector, giving a better experimental flux at the outer face, and also that there are 4 in. of graphite between the inner face of the beam tube and the core—important for safety. A 2 ft cube opening in the shield for the beam tubes serves as an instrument cave. Extending from the exit face of the beam tube to the outer face of the biological shield, the openings are filled with barytes concrete shielding blocks. Using this, experimental apparatus can be placed nearer the reactor core for neutron beam work.

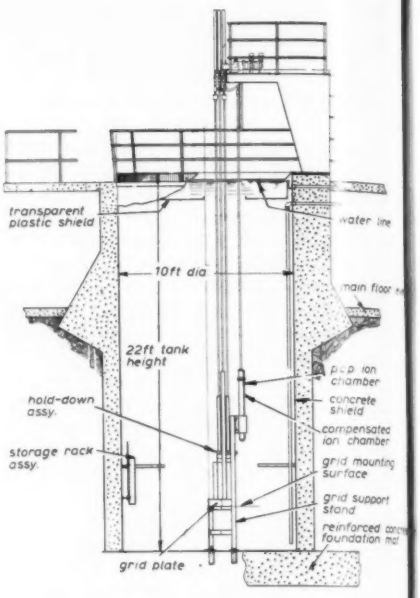
Other optional experimental facilities include a thermal column extending from the reflector to the outer edge of the shield, a hydraulic rabbit mounted on the railing of the operating platform, a pneumatic rabbit into the core, a 4 or 6 in. through tube and an isotope production facility. A hot cell can be incorporated into the pool wall opposite from the core, linked to the pool by a special underwater through tube.

10 kW POOL | *AMF Atomics*

Needing a total water depth of 22 ft, this model can be installed either above or below ground. It has a larger



ACF core is common to both their 1 W and 10 kW Pool Test Reactors. It comprises 25 MTR-type fuel assemblies in a supporting grid with 54 available lattice holes



AMF tank—first of these 10 kW reactors was built for the Dutch 'Het Atoom' exhibition in 1957 and is now in operation at Delft University at an increased power of 100 kW

version of the AMF design grid used in their 10 kW pool—this time the lattice is a 6 × 9 grid—and needs a correspondingly larger critical mass. Control drive mechanisms are also standard AMF design and the control and instrumentation system has features proved on the larger AMF reactors. Experimental facilities available are the same as those of the 10 kW pool.

PTR 604 & PTR 605 | *ACF Industries*

The ACF Pool Training Reactors are available in two models covering several power levels, varying from 10 watts to 10 kW. In both all basic reactor components and systems are prefabricated and shipped to the site for final assembly. With this 'building block' method the irradiation facilities can be varied according to the customer's needs. Also the customer may provide certain parts directly, such as the tank and shield, in which case ACF provide only the design and installation supervision of these parts. This reduces the amount of foreign exchange when selling abroad and accounts for the wide variation in their price quotations—$125,000 to $250,000.

Although the two models available, 604 and 605, use different tanks and shielding, their major components—grid plate, fuel assemblies, control rod and drive mechanisms, instrumenta-

tion and control systems, and console—are the same in both, should conversion to higher power be required.

The basic 604 design is for 10 watts but with more shielding and a small quantity of additional fuel this level can be increased to 1000 watts. Twenty-five MTR-type fuel assemblies in a supporting grid form the standard core. Enrichment can be either 20 or 93·5%. The 604 tank is welded steel plate, coated on the inside with liquid tile. Dimensions are 10 ft 6 in. deep, 12 ft long, 8 ft wide; additional shielding is given by ordinary concrete blocks stacked round outside. For the 10 kW 605 a 7 ft dia cylindrical tank is used, 18 ft deep, and some heavy concrete is used in the poured shield. This gives protection against the $1{\cdot}3 \times 10^{11}$ flux.

Basic experimental facilities are identical in both models: the thermal column is 2×2 ft at the core end, there are two 6 in. dia beam tubes, one 6 in. through tube and ample space round the core for bulk shielding. Custom design allows the addition of more facilities as required.

THE ARGONAUT TYPES

The Argonne National Laboratory's training and research reactor, called the Argonaut—from Argonne naught power—was put into operation there in February, 1957. It was handed over to the International School of Nuclear Science and Engineering a month later and has been used ever since in training students from 35 countries. Three modified versions of the well-tried original are now available commercially: two produced in the USA and one in Great Britain.

In its design, the main features aimed at were flexibility, versatility, economy of construction, and safety. Its simple construction was proved by the fact that the Argonne staff assembled one from packing cases in five days at the Geneva scientific exhibition. Safety is inherent in the core type—it has a large negative void coefficient and a negative temperature coefficient—and additional safety has been introduced by several mechanical design features. A wide variety of experiments are possible with the Argonaut for instance: external exponential experiments, fuel studies, such as reactivity microscopic flux mapping, shielding and irradiation effects, pile-oscillator measurements, critical mass determination.

Cost of the first Argonaut without fuel was estimated at $100,000 of which a fifth went on a new building, slab and foundations. Maximum operating power is 10 kW thermal with neutron fluxes of about 10^{11}.

The assembly is a graphite cube with a central annular core formed of two aluminium tanks, 36 and 24 in. dia and 24 in. high. In the centre is a cylindrical graphite reflector which can be removed and replaced by a lattice assembly for internal exponential experiments. The fuel elements are MTR-type plate assemblies—a cluster of 17 aluminium plates with dispersed U_3O_8—mounted in the annulus with waterproofed graphite segments between them. This graphite, together with water round the fuel element plates, provides moderation. With this type of arrangement the number and position of the fuel boxes can obviously be altered according to experimental requirements. The annular geometry, although suffering from the disadvantage of a large critical mass, gives a large volume for experiments and is ideal for internal exponential work and testing components.

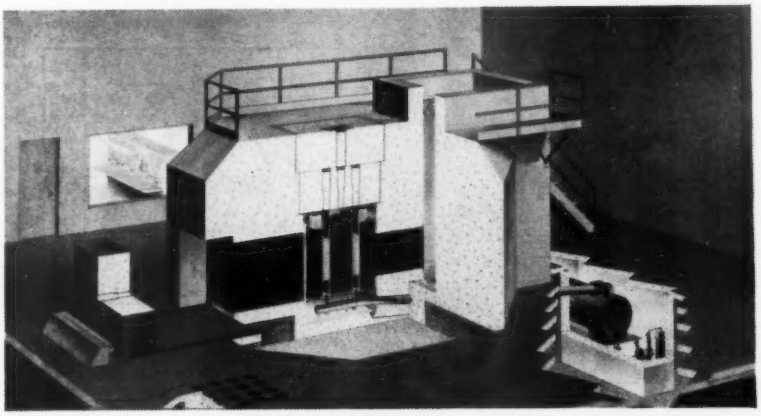
Water circulated through the core annulus acts not only as moderator but also coolant and, by linkage to a dump tank, as emergency shut-down. Supply is mains tap water which is passed through a mixed-bed ion exchanger and then to an aluminium dump tank. A simple heat exchanger is connected in this closed loop. In emergencies the reactor tank can be drained through a six inch dump line controlled by a quick-release flap valve operated by a magnetic clutch. At the same time, an independently operated gas sparging system injects nitrogen bubbles at the bottom of the fuel boxes to reduce moderator density.

Regular operation control is by cadmium plates in slots in the outer reflector near the core tank. There are six available positions, the number of rods depending on the core geometry. All are designed to fail to safety and, with the exception of the fine control, any one rod is capable of shutting down the reactor.

Stacked concrete blocks or monolithic concrete form the main body of the shield whose thickness varies according to the attenuation needed. The top shield is made to be removable by an overhead crane, and the top of the reactor is kept free of mechanisms to give accessibility for loading fuel assemblies and installing experiments.

Against one face of the graphite cube is a graphite thermal column. The dimensions of this and the number of ports vary in the three commercially available models. Against another face is a removable water tank, mounted on a flat-bed truck running on rails for shielding experiments.

Activated fuel elements are transferred from the reactor to a fuel storage pit in the concrete floor near the reactor in a lead coffin. For this a jib crane is installed, used also for handling the top shield units.



UTR 10 features a rectangular graphite prism as moderator surrounding two open-top core tanks housing the fuel. Unlike its forerunner the Argonaut, the shield experiment tank is inside the main reactor shield

UTR 10 | *American-Standard*

The main difference between American-Standard's University Training Reactor and the Argonaut lies in its core design. Here the annular geometry has been abandoned in favour of a fixed two-slab arrangement with a rectangular graphite reflector between them. Two open-top core tanks, 18 in. apart, are centrally positioned within 4 in. square graphite blocks. Each tank is equally subdivided into six fuel chambers and the fuel elements arranged vertically midway between these chambers. This configuration gives approximately one foot of graphite reflector in all directions. Critical mass loading is about 3 kg U-235, and fuel lifetime around 10

years, fission product build-up and burnup being the controlling factors. Two types of plate can be used: for the American market uranium of 90% or greater enrichment is contained in solid solution with aluminium; for overseas 20% enriched U_3O_8 in an aluminium matrix is used. Built-in excess reactivity is limited to 0·5%.

Control is by four cadmium elements: two safety, one shim-safety, and one regulating. The safety rods normally remain out of the core and are only inserted during scram operation. The shim-safety and regulating rods with their reversible drive mechanisms, give coarse and fine control respectively.

Total of 22 access ports

Maximum flux in the internal reflector is in the order of 10^{11} and five vertical graphite stringers are provided for specimen irradiation. Here absorption cross-section measurements by the danger coefficient or pile oscillator methods are made.

Total, fission, and scattering cross-section measurements can be performed in two 6 in. dia beam ports extending through the concrete shielding into the internal reflector where they have a removable graphite plug. A concrete shielding plug fills the length of the port outside the reflector and can be replaced with a neutron collimator for experiments requiring a defined neutron beam. Maximum neutron current available is approximately $1{\cdot}5 \times 10^{10}$.

The $5 \times 4 \times 5$ ft thermal column is composed of 4 in. square graphite blocks. Between it and the core is a $1\frac{1}{2}$ in. thick lead curtain to shield personnel from gamma radiation when the outer face is exposed during shutdown. Fourteen $4 \times 4 \times 60$ in. stringers are located symmetrically in the column; one 73 in. long in the centre passes through the lead curtain and the reflector to within an inch of the outer core tank. A concrete closure door mounted on rails gives easy access to the stringers. Flux at the curtain is 6×10^{10} and 10^9 one foot inside the outer face.

Opposite the thermal column a $2\frac{1}{2}$ foot square graphite duct leads into the bottom of a $5 \times 6 \times 11\frac{1}{2}$ ft deep open-top shield experiment tank. An aluminium-plate 'window' incorporated at the water and duct interface prevents shielding water from leaking into the graphite. Peak thermal neutron flux at the water and duct interface is around 10^7; with a fission plate at the interface there is a maximum fission spectrum of the same value.

As well as these reactor physics experiments, nuclear engineering studies of reactor properties can be made, such as critical mass determinations, flux distributions, temperature coefficient of reactivity, core building, control rod calibration, fuel element disadvantage factors, excess k and material shielding properties.

EDUCATOR | *AMF Atomics and GNE*

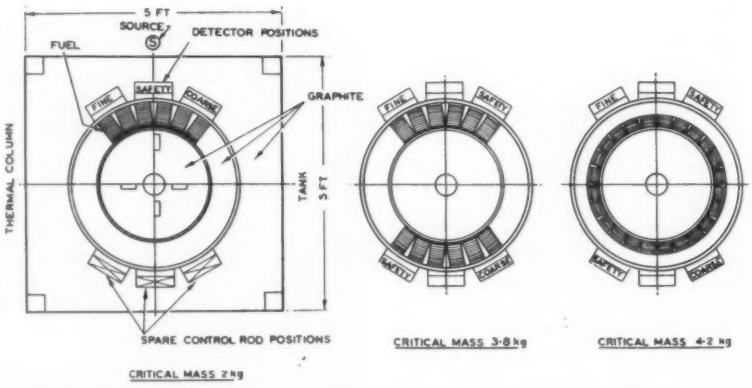
A two-slab core arrangement is also a feature of the AMF Atomics-General Nuclear Engineering Educator. In the $5 \times 5 \times 9$ ft graphite prism there are six aluminium fuel boxes arranged in two rows. These contain a total of 24 fuel bundles, each comprising 11 MTR plates. This arrangement has been adopted by AMF for several specified reasons: first no protective cladding is needed for the graphite because it does not come into contact with the water; secondly, there is no excess volume in the core for additional fuel plates so that the loading cannot be made unsafe. Also there is no possibility of rearranging the pattern to exceed the designed excess reactivity.

The separation of the fuel boxes is used to accommodate 16 vertical foil slots for flux mapping, a facility not available in the UTR-10. It also has six vertical holes in addition to three horizontal beam tubes. By contrast the thermal column has only six access ports instead of the UTR-10's fifteen.

JASON | *Hawker Siddeley*

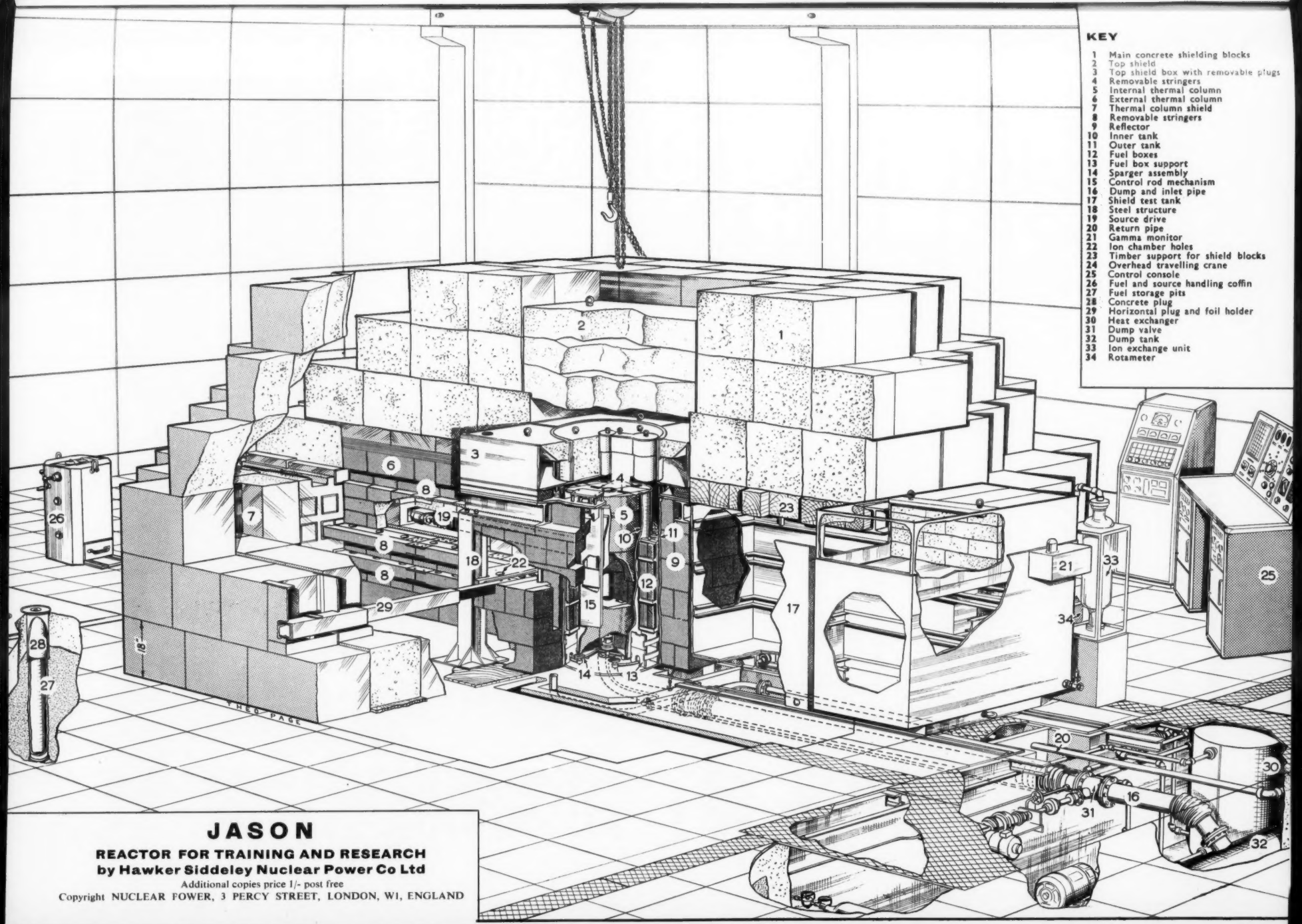
Of the three Argonaut types available, the Jason is the least modified. Marketed by the Hawker Siddeley Nuclear Power Co Ltd, this design retains the annular core and the flexibility inherent in this geometry. Modifications made have resulted largely from the need to satisfy British standards of instrumentation and control. One difference in layout is that the dump tank has been moved round to a new position under the shield tank rails, which is more economical on floor space.

The aluminium annular core is 4 ft high with an inner tank of diameter 2 ft and outer 3 ft. The internal graphite reflector contained in the inner tank has five full-length removable stringers; for larger experiments this can be removed as a unit provided that the fuel has first been unloaded. Dido-type fuel plates in assemblies of 3×6 in. are used which are the same height and width as the MTR design. These can be loaded into the core in three possible configurations with associated critical masses varying from 2 to 4 kg, as shown in the figure. The number of control rods varies accordingly. Excess reactivity is 0·5% although more may be held down by experiments installed prior to core fuel loading. Control is by cadmium sheet as usual: 1 or 2 safety, 1 or 2 coarse, 1 fine, according to core loading and excess reactivity.



JASON'S annular core, a direct inheritance from the Argonaut, provides a choice of three fuel configurations. Each fuel box contains 30 DIDO-type fuel plates

Like the UTR-10, Jason has a thermal column with 14 ports, two 4×4 in. beam holes and a shield tank. The annular geometry provides an ideal driving lattice for internal buckling measurements and the null reactivity method of determining k_∞ for proposed power reactor fuel element assemblies, the internal core tank giving ample space for water or organic-moderated lattices. Also the effect of small changes in design, burnup, etc can be measured by oscillating samples in the central cell of the test lattice where the neutron spectrum approximates to that in an infinite assembly. Thus small changes in



JASON

REACTOR FOR TRAINING AND RESEARCH

by Hawker Siddeley Nuclear Power Co Ltd

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Laboratory reactors—quick reference data

1 NAME	TRIGA II	AGN 201	AGN 211	AGN 451	UTR 10
2 TYPE	swimming pool	solid homogeneous	swimming pool	swimming pool	Argonaut type
3 MAKER	General Atomic	Aerojet-General Nucleonics	Aerojet-General Nucleonics	Aerojet-General Nucleonics	American-Standard
4 POWER	10 kW	0·1 W nominal 20 W max	1 W	100 W	10 kW max
5 THERMAL NEUTRON FLUX m/cm²/s	4×10^{11} max	5×10^{6} nominal 10^{8} at 20 W	3×10^{7} max	3×10^{9} max	10^{11} max
6 CORE	lattice of cylindrical fuel elements and graphite dummies	homogeneous: U235/ polythene mixture	16 UO_2/polythene elements in Al grid	12 UO_2/polythene elements in Al grid	rect. graphite prism 2 core tanks, 12 elements
7 CRITICAL MASS	2 kg	656 g	1 kg	800 g	3 kg
8 ENRICHMENT	20%	20%	20%	20%	20—90%
9 ELEMENT	U/ZrH rods, Al clad	——	UO_2/polythene mixture rods, plastic coated	UO_2/polythene mixture rods, plastic coated	MTR plates
10 MODERATOR	ZrH	polythene	polythene	polythene	H_2O & graphite
11 COOLANT	H_2O	——	H_2O	H_2O	H_2O
12 REFLECTOR	graphite, Al clad	graphite	graphite	graphite	graphite
13 TEMPERATURE COEFFICIENT	-8×10^{-5}/°C	$-2{\cdot}5 \times 10^{-4}$/°C	$-3{\cdot}6 \times 10^{-4}$/°C	$-3{\cdot}6 \times 10^{-4}$/°C	$-1{\cdot}69 \times 10^{-2}$/°C
14 EXCESS REACTIVITY	0·7%	0·2%	0·2%	0·2%	0·5%
15 CONTROL	B_4C rods: 1S, 1C, 1F	U-containing rods 2S, 1C, 1F	boral sheet: 2S, 1C, 1F	1F, 1C (boral sheet) 2S (B_4C)	4 Cd rods
16 SHIELDING	concrete, H_2O	H_2O, Pb	H_2O, concrete, Pb	usually underground	concrete
17 EXPERIMENTAL FACILITIES	thermal column 3 hor. beam tubes 1 vert. beam tube rotary specimen rack pneumatic rabbit	glory hole 4 access ports vertical thermal column	as required: thermal column vert. glory holes	as required: thermal column vert. glory holes	thermal column, 15 ports internal column, 5 ports 2 beam tubes shield tank
18 OPERATING SPACE NEEDED	50 × 30 × 24 ft	16 × 16 × 12 ft	20 × 20 × 14 ft	pool 21 ft deep, 5 ft dia surface 20 × 30 × 30 ft	38 × 42 × 17 ft
19 APPROXIMATE COST	$145,000 basic	$100,000	$100,000	$125,000 basic	$175,000
20 NOTES	Triga I: below ground version, similar but no thermal column & no beam tubes. With forced cooling, 30 kW model available	May be operated at 20 W continuous, 1 kW intermittent with concrete shielding	Core configuration flexible; may be operated at 100 W continuous, 1 kW intermittent	With MTR Al clad elements containing 3·5 kg U-235, power up to 100 kW, flux 10^{13}, for isotope production	Domestic market: fuel is 90% U in solid soln. with Al. Foreign market: 20% U_3O_8 with Al

design need not result in a demand for new fuel elements. Fine structure data may also be obtained in the internal region.

Access to this region means that pile oscillator measurements can be made without any scattering correction. A heavy water tank may be substituted for the central graphite column to give a well-thermalized spectrum at the point of maximum thermal flux. Alternate use of D_2O and graphite would enable samples to be oscillated in well-thermalized and hardened spectra and will yield information on resonance spectra.

If the reactor is to be used primarily for radiation and beam work and core flexibility is of little importance, the single slab configuration is all that is needed.

L77 | *Atomics International*

This reactor is the latest in a very long line of aqueous homogeneous types, the first of which was LOPO—built as long ago as 1943 at Los Alamos. Others such as HYPO and SUPO followed and in 1948 Atomics International (North American Aviation) took up the development, eventually installing reactors of this type in Germany, Italy, Japan, Denmark and the United States. Most of these are either of 1·5 or 50 kW and in 1957 it was decided to offer a much less powerful version (10 watts) which could be completely factory assembled as a 'package,' suitable for installation with the minimum of fuss in an existing building, would give a reasonable amount of experimental facilities with moderate cost and save further expense by the avoidance of high-trained staff to operate it.

This type of reactor was for a long time called a 'water-boiler' but this was a complete misnomer as the solution never boiled under normal operating conditions: they are now more commonly known as solution type reactors. The L-77 is extremely simple and consists basically of a stainless steel spherical vessel containing a criti-

L 77 production line shows assembly of the spherical core containing the uranyl sulphate solution into the three-region shield, at left, which fits into the 8 ft dia steel containment tank on the right

JASON	EDUCATOR	L 77	PTR 604 605	AMF TANK	AMF POOL	
Argonaut type	Argonaut type	solution	swimming pools			2
Hawker-Siddeley	AMF—GNE	Atomics International	ACF	AMF	AMF	3
10 kW cont.	10 kW	10 W	1—10 W 10 kW	10 kW	10 kW	4
$1{\cdot}5\times10^{11}$ max	$1{\cdot}8\times10^{11}$ max	2×10^{8} max	$1{\cdot}3\times10^{7}$ at 1 W $1{\cdot}3\times10^{11}$	$7{\cdot}7\times10^{10}$ av	$1{\cdot}3\times10^{11}$ max	5
Al annulus, 3 core configs. possible	rect. graphite prism, 2×3 fuel boxes	U_2SO_4 soln. in $15\frac{1}{2}$ in. dia. s.s. spherical vessel	25 MTR type fuel assemblies in supporting grid plate	6×9 grid	5×6 grid	6
2—4 kg	4 kg	1395 g	3·3 kg (20%) or 3·0 kg (90%)	3·6 kg	2·38 kg	7
20—90%	20%	20%	20 or 90%	90%	90%	8
DIDO plates	MTR plates	——	MTR type	MTR type	MTR type	9
H_2O & graphite	H_2O & graphite	H_2O	H_2O	H_2O	H_2O	10
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	11
graphite	graphite	see shield	graphite & H_2O	H_2O	graphite & H_2O	12
-10^{-4}/°C		$-0{\cdot}263$/°C	$-1{\cdot}21\times10^{-3}$/°F	$-1{\cdot}05\times10^{-4}$/°C		13
0·5% More held by exp. installed prior to fuel loading	0·5% max	0·5%	0·4 – 0·5%			14
Cd sheet 1—2S, 1—2C, 1F	4 Cd blades	Cd cylinders: 1C, 1S	2S (B_4C), 1C (s.s.)	3S (B_4C), 1C (s.s.)	2S (B), 1C (s.s.)	15
concrete	concrete	3 regions comprising lead, diphenyl, boron & paraffin mixtures	H_2O, concrete	H_2O, concrete	H_2O, concrete, Pb	16
thermal column, 14 ports internal column, 5 ports 2 beam tubes shield tank	thermal column, 6 ports 3 vertical beam tubes 6 hor. beam tubes shield tank with beam tube 16 vert. foil slots	2 beam tubes 5 exposure tubes (1 main, 4 aux) 1 radioactive gas tube 2 spare instrument thimbles	basic: thermal column 2 beam tubes through tube bulk shielding	as required: beam tubes rabbits thermal columns through tubes bulk irradiation area isotope prodn. facility	basic: 4 beam tubes bulk irradiation area as required: thermal column rabbits through tubes isotope prodn. facility	17
$35\times45\times20$ ft	2000 sq ft $\times$ 21 ft	$20\times20\times12$ ft	17 ft high 30 ft high	23 ft dia. $\times$ 30 ft		18
£50,000	$175,000	$100,000	$125,000—$250,000	$145,000	$160,000	19
3 core loadings possible		Core and triple shield suspended in 8 ft dia, 7 ft deep water-filled shield tank	604 will operate at 1 kW with extra shielding 604 rectangular tank 605 cylindrical	above or below ground		20

cal mass of 20% enriched uranyl sulphate solution. The vessel has a wide opening at the top communicating with a dome of diameter rather more than that of the opening. In the event of any expulsion of solution during a power excursion it overflows into the dome. This immediately reduces reactivity which is a valuable inherent safety feature. Control is by two rods working in vertical thimble tubes extending right through the dome and sphere. The poison sections of the rods contain cadmium, the upper, lead as a reflector and shield.

One problem in this type of reactor is that of radiolytic decomposition and the L-77 incorporates a platinized alumina catalyst unit inside the dome. In operation, the sphere is maintained at a vacuum of about 24 inches of mercury. The larger solution reactors have internal cooling coils in the sphere but on the L-77 with only 10 watts to be dissipated, none is required.

The core is contained inside a three-region primary shield which also acts as a reflector. This whole assembly is contained in a cylindrical stainless steel vessel 43 in. dia which in turn is fixed at the centre of an 8 ft dia steel tank filled with ordinary water.

The main exposure tube (1·37 in.) runs right through the centre of the core and there are also four smaller exposure tubes (0·75 in. dia) going right through. Two stepped beam tubes (1·87/3·23 in. dia) run from the tank walls to the surface of the core. There are also four instrumentation thimbles which run beneath the core: two of these are spare and can be used for experimental work. Finally, the vacuum line allows fission product gases to be used as a gamma source. The equilibrium activity is about 10 curies at the maximum thermal flux of 2×10^{8}; gamma flux at the centre is about 2000 R/h.

The manufacturers list 118 isotopes having specific activities greater than 10 dps/g which can be produced in one hour's irradiation. Of these 73 have half-lives short enough to allow normal disposal after decay. Twenty of them have half-lives so short that they are not commercially available.

Many useful reactor experiments may be carried out using a pile oscillator device. These include cross-section determinations, delayed neutron fractions and prompt neutron lifetime. The reactor can also be used for demonstrations of flux plotting, shielding studies, cross-sections by danger coefficient method, fission gas activity and build up, and radiolysis of water.

AGN 201 | *Aerojet-General Nucleonics*

The characteristic common to all three low power reactors marketed by Aerojet-General Nucleonics is their homogeneous plastic core. The material used is a dispersion of 20% enriched UO_2 particles embedded in radiation stabilized polythene which acts as the moderator. This mixture is inherently safe, even for reactor transient periods as low as 4 to 6 milliseconds. It results in negligible time delay in heat transfer from fuel to the moderator and the prompt heating of the polythene increases the average thermal energy of the neutrons, resulting in decreased fission-to-capture probability. Also the prompt expansion of the fuel elements cause a decrease in the density of the moderator which increases the leakage of the neutrons out of the core; net result is that the reactor shuts down.

The model 201 is portable, low priced, self-contained and requires no extra shielding. Continuous design power is 0·1 watt when the peak flux is 5×10^{6}. A minimum quantity of uranium is used—critical mass is 656 g U-235 in 20% enriched UO_2—core life is effectively infinite and it provides a high analytical sensitivity for danger-coefficient tests. Typical uses in educa-

AGN 201 is a packaged unit standing only 9 ft high, weighing under 10 tons in operation. Like all the AGN reactors, the core material is a dispersion of uranium oxide in polythene

tion are demonstration of both steady state and kinetic and dynamic behaviour of reactor systems and safe assembly of a critical mass. In addition to training reactor operators and testing for radiation effects, as an applied research tool it may be used for the production and study of isotopes, for activation analysis, pile oscillator testing and as a controlled neutron source to drive exponential assemblies for core lattice design studies. Over 180 isotopes can be produced for use in process control and medical diagnosis.

Plastic fuel in disks

The polythene-UO_2 dispersion is made into nine 10 in. dia disks of varying thickness. Above and below is a high-density graphite reflector and the whole is contained in an aluminium core tank. Round this is a further section of graphite, a 10cm lead shield and, on top of this, the thermal column tank, all in a secondary container, the steel reactor tank. Finally this is supported inside the steel water tank to give the overall reactor dimensions of $6\frac{1}{2}$ ft dia, 9 ft high.

Control is from the bottom by two safety, one coarse and one fine rod. Each contains up to 20 g of U-235 in aluminium cans and acts so that reactivity is increased as the rods are inserted. With a maximum 235 in the coarse rods, each controls about 1·6% reactivity. The control rods pass into the core through holes in the lower four fuel disks.

Startup is achieved by a 10 mc Ra-Be source in the graphite reflector. With safety rods cocked and control rods all the way out, the reactor multiplication generates 30 microwatts and gives indications on all instruments.

Experimental facilities comprise a 1in. dia horizontal glory hole passing through the core, 4 in. dia access ports passing through the reflector outside the core tank, and the thermal column tank. This acts as shield when filled with water or thermal column when filled with graphite. It can be removed to allow the whole core tank or the core tank cover to be taken out.

The 1000 gallons of water in the 201 tank, containing 250 lb of dissolved boric acid, is sufficient biological shielding for continuous operation at powers up to 100 mW. A more powerful modification, 201P, may be operated at 20 W continuously and at 1 kW for short periods and with a 25ft approach limit for personnel. The 201P has added shielding in the form of concrete blocks and additional instrumentation to monitor the higher power levels.

AGN 211 | *Aerojet-General Nucleonics*

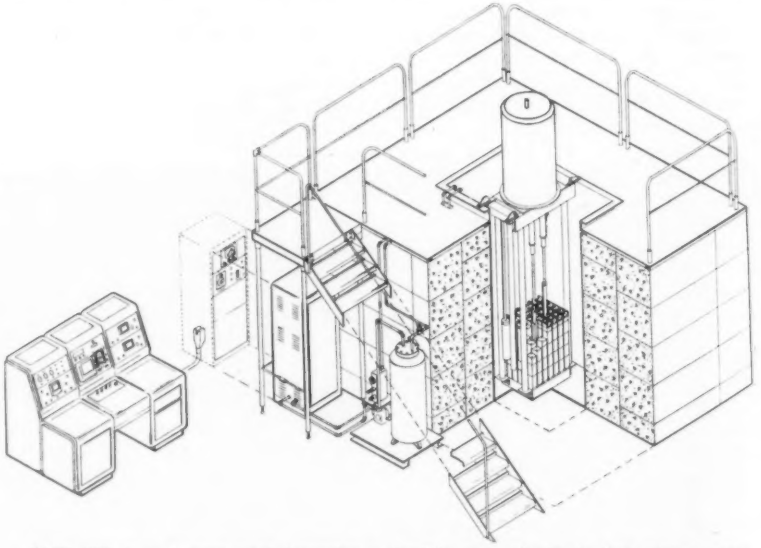
With the exception of its plastic core the AGN 211 is similar in most ways to other small swimming pool reactors. Designed to operate at a power level of 1 watt—with extra shielding at 100 watts — it is compact, semi-portable and has a flexible core geometry. Critical mass is 1kg and maximum thermal flux is 3×10^7.

Like the 201, the AGN pool has application not only as a university and research centre experimental facility for training, but also as a neutron source for medical and scientific use and for industrial process control.

Typical experiments which may be performed are: flux distribution as measured by foils, shielding measurements, control rod calibration and effectiveness, effect of absorbers on reactivity and flux distribution, effect of using different reflector materials, effect of altering the lattice arrangement.

The fuel mixture occupies the centre 12 inches of each 33 in. long plate. Above and below this is 6 in. of carbon reflector. At the top is a 2 in. lead shadow shield and then an aluminium removal fitting. At the lower end is a 6 in. aluminium mounting and the whole element is doubly coated with impervious resin to protect the UO_2 from the water surrounding each element.

Sixteen elements form the core assembly, each seated into an aluminium grid plate. Surrounding them are 26 graphite reflector elements. The ele-



AGN 211 is a 1 watt pool featuring a flexible core of plastic fuel plates that can be dismantled and rearranged outside the reactor

ments can be easily removed from above and after operating at 1 watt their position in the core can be changed outside the reactor. As a safety precaution the control rod cannot be disassembled without removing at least one fuel element. There are four boral sheet control rods which fit into slots on the edge of the elements.

The standard pool is 40 in. square and 8 ft high, providing 4½ ft of shielding water above the core. Radial shielding is by overlapping concrete blocks 18 × 20 × 40 in. thick. The usual water purification system is incorporated. With 20 inches of additional concrete shielding the 211 can be run continuously at 100 W, 3×10^9 flux, and intermittently at 1 kW, 3×10^{10} flux. This modification is called the 211P. The plastic elements can be used in other swimming pools as replacements for normal bulk shielding elements.

A variety of adaptations make the reactor flexible. The basic pool can be provided with access ports, several inches in diameter, parallel and close to the core assembly, and a 1 in. glory hole through the core, allowing irradiation in a dry field. Some core configurations give water-filled voids for exposure tests, and foils or other thin samples may be put between the fuel element components.

AGN 451 | *Aerojet-General Nucleonics*

Also a swimming pool type, the standard 451 is installed below ground although a surface version is obtainable with extra concrete shielding. The core is smaller than that of the 211—the plastic elements are only 10 in. long compared with 33 in.—and with the optimum core configuration the critical mass is 800g. Design power is 100 watts and maximum thermal flux 3×10^9. Minimum dimensions of the mild steel tank are 5 ft diameter and 21 ft deep.

Experimental facilities are variable including reflector plates to fit in the grid plate, 1 in. holes through the fuel elements etc. With the above ground version a 4 × 4 × 5 ft long graphite thermal column may be installed.

As reactor operators gain experience, it is intended to replace the plastic elements with MTR-type aluminium clad ones containing 3·5 kg of U-235. With this core operating power can be increased to 100 kW—more with forced cooling—and a flux of 10^{12}, allowing a more varied research programme and isotope production.

The core size is then increased to 24 × 15 × 15 in. but other features are substantially the same.

SUBCRITICAL ASSEMBLIES

Model 9000

A cheaper alternative to a reactor for training is a subcritical assembly. The Nuclear-Chicago Corporation are marketing a small packaged unit specially designed for university use, called the Model 9000. Open in construction, this comprises a stainless steel tank, 4 ft dia and 5 ft high containing a lattice of 275 vertical aluminium tubes. Each contains five natural uranium slugs of the type used at Savannah River, with a total loading of 5500 lb, and in the centre of the assembly is a Po-Be neutron source. Moderator and shield is provided by 435 gallons of tap water surrounding the lattice. Central region flux, using five 1 curie Po-Be sources, is about 5×10^4.

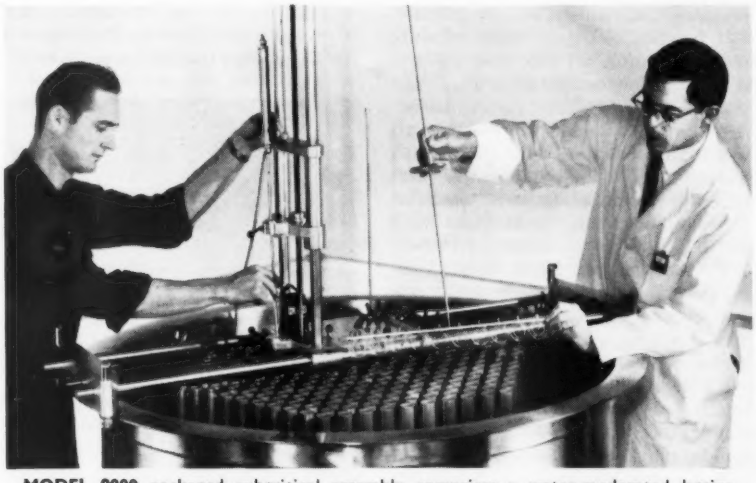
Included with the reactor are a port for an external neutron source, such as a Van de Graaff generator, a storage container for the source, foil handling and positioning equipment, and source handling apparatus. A manual of 30 experiments has been prepared divided into three groups: for training in basic nuclear detecting and measuring devices, methods for determining properties of particles and radiations, and reactor experiments.

The price, complete with walkway, railings and lattice work is $17,500 with another $10,000 to $15,000 for instrumentation.

Uranie

Another commercially-available subcritical assembly is the Uranie, designed and made for the French CEA by SAMES of Grenoble and marketed in this country by Miles Hivolt Ltd. Instead of a radioactive source, this uses an accelerator as its neutron source, giving easy control of the neutron output. Either a continuous or pulsed neutron generator is available. With the former the steady-state performance of the assembly can be studied and with the latter the dynamic characteristics of a reactor predicted. Used alone the pulsed neutron source is a powerful research device.

The assembly itself comprises 1½ tons of natural uranium in 162 rods, each made up of 10 slugs and sheathed in aluminium. Water forms both the moderator and shielding. Diameter of the core is 60 cm and the necessary height for the whole installation is 12 ft. With a simple set of instruments, the cost of the whole installation is £20,000 excluding uranium.



MODEL 9000 packaged subcritical assembly comprises a water-moderated lattice of 275 tubes containing natural uranium in a 5 ft high tank. With it come calibrated positioners for BF_3 counters and a set of positioning rods with foil holders

ADDRESSES OF MANUFACTURERS

GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS CORP
PO Box 608, San Diego, 12, Calif

AMF ATOMICS
261 Madison Ave, New York, 16, NY

NUCLEAR PRODUCTS-ERCO DIVISION OF ACF INDUSTRIES
508 Kennedy Street N.W, Washington, 11, DC

AMERICAN-STANDARD ATOMIC ENERGY DIVISION
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HAWKER SIDDELEY NUCLEAR POWER CO LTD
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ATOMICS INTERNATIONAL
PO Box 309, Canoga Park, Calif

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NUCLEAR-CHICAGO CORP
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MILES-HIVOLT LTD
91 Princedale Rd, Trafford Park, Manchester, 17

concluding . . .

Boiling effects in liquid-cooled reactors

by H. A. ROBERTS, B.Sc., A.K.C., A.M.I.Mech.E.
and R. W. BOWRING, M.A.(Oxon)
Reactor Division, A.E.R.E., Harwell

In the second of a two-part article, the authors deal with boiling heat transfer: the effects of various types of boiling, recent correlations for calculating fuel element temperatures, and reactor safety limits set by burnout

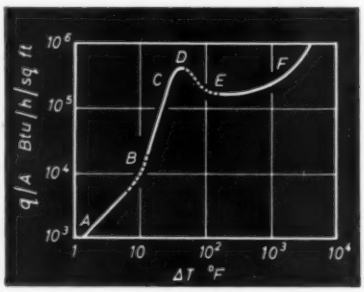
FOR BOTH BOILING and non-boiling reactors, the conditions of particular interest are those relating to flow in vertical channels. However, many experiments leading to a better understanding of the processes involved in boiling and whose results may be readily adapted to reactor conditions have been performed with 'pool boiling' apparatus. This type of apparatus is comparatively cheap and simple to construct, usually taking the form of a vertical or horizontal heating element, submerged in liquid, contained in an open or pressurized vessel.

Nukiyama *(28)*, in 1934, using such an apparatus, measured the heat flux, q/A, from a submerged horizontal platinum wire in water at atmospheric pressure and saturation temperature as a function of the difference between the temperature of the wire T_w and the saturation temperature T_{sat}. The shape of this familiar 'boiling curve' (fig 7) may be explained by dividing it into a number of boiling regimes, each with a different mechanism of heat transfer. Recent advances in the interpretation of boiling phenomena have led to new ideas for their correlation. The following description of the boiling curve incorporates these interpretations which are used in the various heat transfer and burnout relationships.

AB represents the part of the curve where heat transfer is to the single phase fluid, taking place by natural convection. The surface temperature at B is above the saturation value, the excess being required to initiate vapour bubbles.

At B boiling from the heater surface commences. At first, bubbles stream from one or two favoured points of nucleation, and these nucleating points become more numerous as the heat flux is increased. In this nucleate boiling regime, BC on the boiling curve, bubbles are formed and may either collapse again if the liquid is very subcooled, or leave the surface as discrete bubbles if the liquid is only slightly subcooled or at saturation temperature. In the later case, the effect of increasing the heat flux is to increase the bubble population and to a lesser extent the production rate.

At C bubbles follow each other so closely that they join together to form continuous oscillating vapour columns. The heat flux rises less rapidly with temperature difference and goes through a maximum at D. The boiling mechanism may be thought of as bursts of vapour rising in columns from near the heated surface with down-jets of colder liquid between, impinging directly on to the heated surface *(13)*. As the temperature difference increases these 'spikes' of liquid decrease in size until eventually there is probably no direct contact between the liquid and the heated surface. The



Curve of heat flux against temperature difference shows the different regimes of boiling (Fig 7)

part of the curve CDE is best named the transition film boiling regime *(30)*. If the critical heat flux at D is exceeded, as may happen in nuclear or electrical heating, the element temperature rises to point F, possibly resulting in burnout. For this reason the burnout heat flux is often regarded as synonomous with critical heat flux, mistakenly because other modes of burnout are possible.

At point E on the boiling curve, with the onset of film boiling, the whole character of the boiling mechanism is changed. The heated surface is covered by a comparatively quiet film of vapour, from which large bubbles break away in an orderly manner with a regular frequency and at regular intervals. The heat is transferred through the vapour film by conduction, convection and radiation. As the heater temperature rises still further, radiation becomes predominant and the heat transfer rises to F and beyond.

The main regions of interest of the boiling curve with respect to nuclear reactors are *a*. the nucleate boiling regime, where a boiling reactor may be expected to operate, *b*. the maximum or critical heat flux because of its application to burnout, and *c*. the minimum heat flux and film boiling regime, because the heat transfer under these conditions determines the rate of rise of temperature of a fuel element when the critical temperature difference has been exceeded.

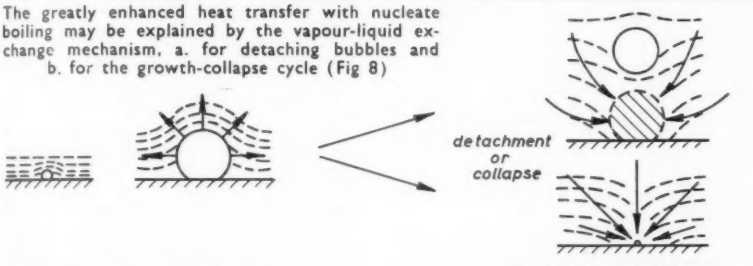
NUCLEATE BOILING HEAT TRANSFER CORRELATIONS

The most satisfactory explanation of the sudden increase in the coefficient of heat transfer at the onset of nucleate boiling is the agitation set up by the bubbles in the boundary layer in contact with the heated surface. The growing bubble pushes superheated liquid into the bulk liquid and on detachment or collapse, draws colder liquid back again to fill the cavity so formed *(31)* (figure 8). Alternative explanations are that the bubble acts effectively as a roughness or that it carries latent heat into the bulk liquid, but these do not give quantitative agreement with the measured heat transfer. The well-established fact that the heat transfer is virtually independent of the degree of subcooling may also be explained by the bubble agitation hypothesis. The effect of subcooling is to decrease the period of the bubble cycle and the maximum radius attained before collapse, and

thus largely to cancel out the effect of the greater temperature gradient. Quantitatively, a 400% increase in subcooling produced only a 15% increase in the product of the parameters determining the heat transfer *(31)*.

Important factors governing the heat transfer in nucleate boiling are the bubble population, the frequency of bubble formation, and bubble dynamics. As depicted in figure 9, each of these factors is dependent upon the degree of superheat which is itself a function of the agitation and thus of the bubble population. Since the bubble population is strongly affected by the condition of the nucleating surface, the degree of superheat for a given heat flux is not an independent variable but is also strongly dependent upon the condition of the nucleating surface *(13)*.

The greatly enhanced heat transfer with nucleate boiling may be explained by the vapour-liquid exchange mechanism, a. for detaching bubbles and b. for the growth-collapse cycle (Fig 8)


detachment
or
collapse
a volume of hot liquid is pushed into the bulk
the bubble detaches or collapses and is replaced by cold liquid from the bulk

Many heat transfer correlations for the nucleate boiling regime have been proposed, but all can be reduced to the form

$$q/A \propto (T_w - T_{sat})^n$$

where q/A = the heat flux, T_w = temperature of heated surface, and T_{sat} = saturation temperature of the liquid.

The value of $(T_w - T_{sat})$ is usually very small and, in consequence, the value of the exponent n is large. The actual value depends very strongly upon the condition of the nucleating surface, values as high as 24 having been reported in the literature *(32)*. With prolonged boiling, i.e., with an 'aged' surface, the value of the exponent decreases and $n = 2$–4 is a more usual range of values. There is very little experimental data on the relation between n and the surface conditions. All that can be said is that, in so far as most correlations require a value of n between 2 and 4 to fit the experimental data, it would appear that most surfaces exhibit similar nucleating properties after prolonged boiling.

For water, with forced convection and surface boiling to subcooled water, Jens and Lottes *(33)* have proposed the empirical correlation

$$60\,(q/A^{\frac{1}{4}} = (T_w - T_{sat})\exp(P/900)$$

where q/A = heat flux—$10^6 \times$ Btu/ft²h, P = pressure—psia, and T_w, T_{sat} = temperature of heated surface, and water saturation temperature—°F.

The equation was derived from data covering a range of pressure 85–2500 psia, mass velocity $(0{\cdot}08$–$7{\cdot}6) \times 10^6$ lb/ft²h, water temperature 300–600°F and heat fluxes up to $2{\cdot}5 \times 10^6$ Btu/ft²h.

No velocity term was found necessary to correlate the experimental data. This may be explained by comparing the role of velocity in single phase and boiling heat transfer. In the boiling case, the laminar region does not exist in the usual sense and the effect of velocity on the eddy diffusivity of the boundary region should be virtually negligible compared with the action of the bubbles in pumping liquid from the boundary layer into the bulk liquid. Nevertheless, one might expect velocity to have a slight effect on heat transfer, particularly at the lower heat transfer rates in the nucleate boiling regime where a dependence on the 0·17 power of velocity has, in fact, been reported *(34)*.

For liquids other than water, there is no correlation directly applicable to the reactor case, i.e. heat transfer to a liquid flowing in a vertical channel with surface or bulk boiling. Fortunately, more generalized correlations, bringing in the physical properties of the liquid and derived from pool boiling data saturation temperature, may be used. It is well established that, referring to the heat flux versus wall temperature curve for heat transfer with forced convection to a subcooled liquid (figure 10), there is, for each value of velocity, a point P_1 on the curve such that for heat fluxes higher than P_1 the relation between heat flux and superheat $(T_w - T_{sat})$ is essentially the same as for pool boiling and independent of subcooling. P_0 corresponds to the value of heat flux where the single-phase forced convection heat transfer line, if produced, intersects the pool boiling correlation line. It has been shown that for a variety of liquids and velocities the ratio of the heat fluxes corresponding to points P_1 and P_0 is approximately 1·4 *(31)*.

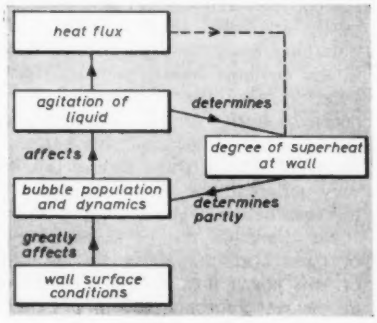
To calculate the wall temperature for a given set of conditions, the heat flux at P_0 may be calculated from the pool boiling and forced convection non-boiling correlations and thus the value at P_1. Above this heat flux, a saturation temperature pool boiling correlation should be used; below, an approximate value may be estimated either from the correlation of Poletavkin and Shapkin *(34)*, or, approximately, probably to sufficient accuracy for reactor applications, by graphical interpolation.

Concept of dimensionless groups

Many saturation temperature pool boiling correlations have been proposed, but the most successful and universal in application are those employing the concept of dimensionless groups. Rohsenow *(35)*, and later Forster and Zuber *(7)*, used the relation $Nu_b = f(Re_b, Pr)$, similar to that familiar in single phase heat transfer. The bubble Nusselt and Reynold Numbers contain a characteristic length and velocity. Rohsenow took these as the maximum bubble diameter and the average mass velocity of vapour at the heated surface respectively, while Forster and Zuber took them as the instantaneous values of the bubble radius and radial velocity, the product of which (Rdr/dt) would be constant as discussed in Part I last month. The physical interpretation of the difference between these two correlations is that the break-up of the boundary layer is assumed to be caused, in the Rohsenow correlation, by bubbles as they are about to leave the heated surface, and in the Forster-Zuber, by the expansion of the bubbles as they grow.

More recently Forster and Greif *(31)*, again using dimensional analysis, have proposed two new correla-

In nucleate boiling, heat transfer is governed by the population, frequency of formation, and dynamics of the bubbles, which in turn depend on the degree of superheat and agitation (Fig 9)



tions. The first is more accurate for each particular liquid, takes pressure into account, but contains an arbitrary constant. The second, although less accurate, is more universal and fits a wide variety of liquids.

Comparison of correlations

Generally speaking, the correlations discussed bring in most of the same fluid and surface physical properties but differ considerably in their relative importance (table I). This is particularly true with regard to the value of the exponent n of the degree of superheat. Both the Forster-Zuber and the Forster-Greif correlations contain an excess pressure term which, to a first approximation, may be taken as proportional to the degree of superheat.

Rohsenow has, however, pointed out that Forster and Zuber, in evaluating the empirical constants in their correlation, used critical heat flux data only. Re-evaluating these constants, using data obtained for the whole nucleate boiling regime, the value of n was increased from 2 to 2·85, in much closer agreement with his own value of 3 (discussion *36*). Forster and Greif showed that, to a better approximation, the excess pressure term increases more rapidly than the degree of superheat and that in their correlations the value of n increased from as low as 2·1 up to at least 3·5.

Thus it may be seen that there is considerable discrepancy between the various correlations and this may be partly attributed to the difficulty of obtaining accurate experimental data in the nucleate boiling regime. However, in that the correlations were derived from similar experimental data, the values of heat flux calculated from any of them should not be very different for conditions similar to those of the original experiment.

No allowance can be made in any of these correlations for the pattern of two phase flow in pipes. Perhaps the nearest approach to this is in the correlation of Dengler *(37, 38)* in which the two-phase heat transfer coefficient is correlated with the Martinelli *(23)* parameter, X_{tt}, for two-phase turbulent flow.

The position regarding nucleate boiling heat transfer in nuclear reactors may be summarized as follows:
a. Usually no great accuracy is required since the temperature of the fuel element would only be some tens of degrees above the prevailing saturation temperature.
b. For water, the Jens and Lottes equation may be used. It includes a pressure term, derived from experimental data up to 2500 psi. Terms for subcooling and forced convection velocity do not appear as their effect is small. The equation is simple in form and suited to computer use.
c. For other fluids, different correlations must be used. The effect of velocity and subcooling, although small, may be taken into account for low heat fluxes by the method suggested by Forster and Greif. At higher heat fluxes, one of the saturation temperature pool boiling correlations may be used. There are many of these and with the limited evidence available it is not possible to say which would be the most reliable for a new set of conditions. However, although they differ on the relative importance of the fluid and surface properties, they are in limited agreement that the heat flux is proportional to $(T_w - T_{sat})^n$ where n is between 2 and 4. This value of n seems to be generally valid for surfaces aged by continuous boiling although much higher values are possible for newly prepared ones.

TABLE I Relative importance of parameters in five heat transfer correlations

	ROHSENOW *(35)*	FORSTER-ZUBER *(7)*	FORSTER-ZUBER MODIFIED BY ROHSENOW *(36)*	FORSTER-GREIF I *(31)*	FORSTER-GREIF II *(31)*
degree of superheat, ΔT	3	1·24	2·1	1	
excess vapour press, Δp		0·75	0·75	1·4	2
saturation temp, T_{sat}				0·4	1·25
liquid thermal cond, k	5·1	0·79	8·55	0·87	0·8
liquid specific heat, c	−2·1	0·45	−6·45	0·55	0·45
liquid viscosity, μ	−4·1	−0·29	−8·05	0·13	−0·3
liquid density, ρ_L	$(\rho - \rho_v)^{0·5}$	0·49	1·35	0·4	0·5
vapour density, ρ_v		−0·24			
latent heat, λ	−2	−0·24	−1·1	−0·8	−1·5
surface tension, σ	−0·5	−0·5	−1·1	−0·8	−1·5
contact angle, β	−1		−0·5	−1	−0·5

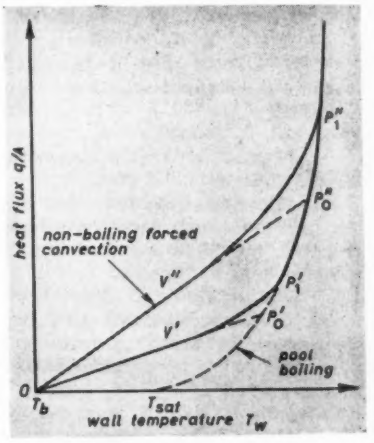
Heat flux is proportional to the product of the physical properties raised to the powers listed in the table

BURNOUT

On safety and plant reliability grounds overheating of the fuel, or burnout, is a serious limitation common to all nuclear reactors. For gas coolants it represents the inability of radiation, fluid, and eddy conductivity, processes to keep the element temperature below failure point. These heat transfer processes are well-known and predictable by established equations. For liquids, failure may occur because the coolant has been replaced by vapour, due to evaporation either in the vital region close to the wall or in the flow channel. Processes which may lead to these conditions are *a.* total evaporation of the coolant, *b.* separated liquid and vapour flow, *c.* liquid deficiency in bulk boiling, and *d.* exceeding the critical heat flux. In reactor work, the last of these processes is of greatest importance and is the main subject of this section. A brief explanation of the other modes of burnout is necessary because they may be involved under certain circumstances.

Total evaporation can be predicted from the flow rate, the heat input, and the fluid properties. It may arise in plant as a result of unstable flow, flow reversal, sonic choking, or pump failure.

A flow of liquid and vapour may become completely separated in a horizontal or inclined channel by gravity and burnout may then occur in the vapour region. Normally, liquid-cooled reactor channels are vertical, although ship reactors may be subjected to listing or rolling. However, for bulk boiling no difference in burnout heat flux was detected experimentally between vertical channels and channels inclined at an angle of 45° to the horizontal, other conditions remaining the same *(39)*.

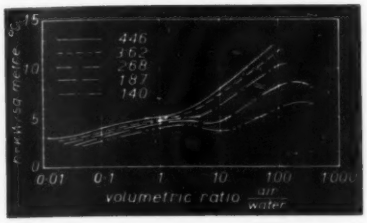


Typical heat transfer curves for forced convection, with and without nucleate boiling (Fig 10)

For the case of liquid deficiency, burnout is probably associated more with a change in the flow pattern of the two-phase mixture. In annular (climbing film) flow, the liquid phase exists principally as a stable film on the channel walls. The conditions for the removal of the liquid film are related to the pressure, vapour velocity,

the film thickness, evaporation rate, inclination of the channel and surface conditions.

There has been no attempt to correlate burnout heat flux with flow regime although a certain amount of work has been done on the heat transfer side. For an air-water mixture, the heat transfer coefficient was found to vary with volumetric ratio as shown in figure 11. The large changes in slope were associated with changes in



Heat transfer to a two-phase, air-water mixture depends on the air-water volumetric ratio and the liquid mass velocity (Fig 11)

flow pattern, the maximum heat transfer coefficient occurring at the transition from slug to annular flow (*40*).

For a steam-water mixture at low pressures and with constant mass velocity, both heat transfer coefficient (*41*) and burnout heat flux (*42*) increase with steam quality, reaching a maximum at a quality dependent upon the mass velocity, and finally decreasing to a very low value at 100% steam quality. This result, which at first sight may appear surprising, is probably accounted for by the large volumetric expansion of the steam on evaporation causing an increased water velocity with perhaps a change in flow pattern (fig. 12). At high pressures the burnout heat flux decreases monotonically with increasing steam quality (*39*, *42*).

Critical heat flux has already been introduced and although it is perhaps the most important in the reactor context, it should be emphasized once again that it is only one form of many burnout variants.

In reactor applications, the burnout data of interest, depending upon the type of reactor, are those relating to flow in vertical channels at a subcooled or saturation temperature.

BURNOUT CORRELATIONS

For subcooled water flowing upwards through vertical channels, Jens and Lottes (*33*) examined a considerable amount of experimental data and proposed the following relation between burnout heat flux, mass velocity, subcooling, and system pressure:

$$(q/A)_{Bo} = CG^{m}(T_{sat}-T_b)^{0\cdot22}$$

where $(q/A)_{Bo}$ = burnout heat flux (10^6Btu/ft²h)

G = mass velocity (10^6lb/ft²h)

T_{sat}, T_b = saturation and bulk water at the point of burnout (°F)

C, m = constants dependent upon pressure, given in the table below

PRESSURE (*psi*)	m	C
500	0·16	0·817
1000	0·275	0·626
2000	0·500	0·445

The equation was derived from data obtained for a 24·6 in. long, 0·226 in. i.d. round tube under the following conditions: pressure 500–2000 psia, subcooling 5·5–163 °F, mass velocity (0·96–7·8) × 10^6lb/ft²h. The overall deviation of the measured burnout heat flux from the correlation value was +18%, −0%.

An equation, similar in form and obtained under fairly similar conditions, was later proposed (*43*) for the pressure range 2000–3200 psia:

$$q/A = CG^{\frac{1}{2}}(T_{sat}-T_b)^{1/3}$$

where C is proportional to $(1-\rho_v/\rho_L)^{1\cdot8}$ and ρ_L, ρ_v are the water and steam densities at the saturation temperature.

Bulk boiling

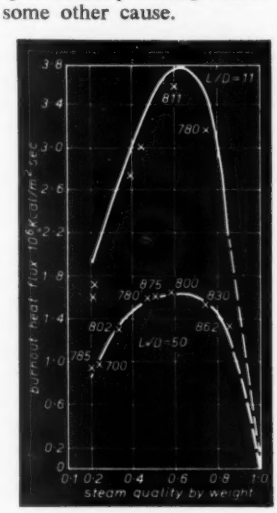
These equations are clearly invalid at zero subcooling, i.e. for bulk boiling, where the predicted burnout heat flux would be zero according to the equation. Further work by the Westinghouse Atomic Power Division on burnout in the bulk boiling region resulted in a modified equation, with the burnout heat flux a function of mass velocity and bulk water enthalpy instead of subcooling (*39*). Later, a correlation factor was added to take account of the length to diameter ratio of the heated channel (L/D effect), and the inlet temperature (*44*). The final correlations proposed for the equivalent enthalpy range 20 °F subcooling to 100% steam quality, and at a pressure of 2000 psia, were either

a. $(q/A)_{Bo} = 0\cdot60\,F_c\,(G)^{0\cdot7}\,(H)^{-0\cdot8}$

or b. $(q/A)_{Bo} = 0\cdot30\,F_c\,(H)^{-3\cdot0}$

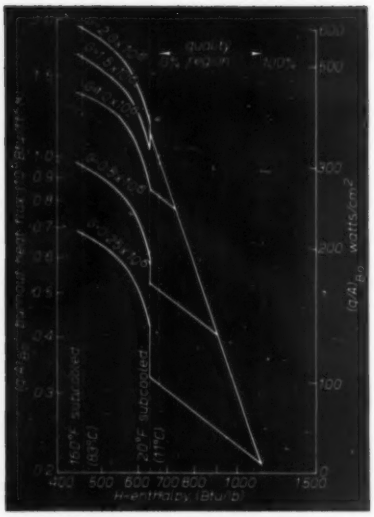
where H (in 10^3 Btu/lb) is the bulk enthalpy at the point of burnout, $(q/A)_{Bo}$ and G as before, and F_c (<1) a dimensionless correlation factor. The burnout heat flux to be taken was the lower value calculated from equations a. and b. It was further recommended that at 2000 psi pressure and for more than 20 °F subcooling at the burnout point, the Jens and Lottes equation should be used but modified by the inclusion of the same correlation factor F_c to reduce the predicted burnout heat flux. Burnout heat fluxes, calculated from these equations, are shown in figure 13. Experiments at lower pressures showed that the burnout heat flux at 830 psia was approximately the same as at 2000 psia for equivalent fluid conditions at the burnout point, but was about 30% greater at 1215 psia (*45*).

It must be emphasized that these are design equations and fulfil a very different function from normal correlation equations giving the best fit of the experimental results. They are aimed at giving a conservative estimate of the *burnout heat flux* and are thus based upon the lowest burnout values obtained experimentally for each set of conditions. On the other hand, when finding the best fit of an equation to a set of burnout data to determine the *critical heat flux*, some of the lowest values obtained may be legitimately discarded because of the lack of reproducibility through instability or some other cause.



Variation of burnout heat flux with exit steam quality for water. In both curves, pressure = 26 atm, flow velocity = 850 kg/m²sec (Fig 12)

The Westinghouse equations were based on a large number of results and represented a variety of conditions—nuclear and electrical d.c. heating; uniform and cosine heat flux distribution along the test section; round and rectangular cross-section channels of zircaloy, nickel, and stainless steel; vertical and inclined test sections; up-flow and down-flow with mass velocities from (0·02–4·8) × 10^6 lb/ft²h, and bulk enthalpies at the burnout point equivalent to 70 °F subcooling to 100% steam quality. These results have been published separately (*46*) and summarized at various conferences (*45*, *47*). Briefly, it was found that apart from the effect of mass



Combination of Jens and Lottes, and Westinghouse, burnout correlations for water in tube-flow at 2000 psia as recommended by the Bettis sub-committee (Fig 13)

velocity and enthalpy, there was no significant difference in burnout results for this range of conditions except that burnout occurred at a higher heat flux, a. for rectangular channels than for round tubes (*48*), and b. for nuclear heating than for electrical, although the latter was by no means conclusive.

Effect of the L/D ratio

Two other empirical correlations have been suggested by the Westinghouse group, one by Sonneman (*49*) and the other at the 1958 Geneva Conference (*48*). In the latter, the form of the equation is slightly different and the correlation factor F_c has been replaced by an exponential term to allow for the heated channel length-to-diameter ratio. Other correlations applicable to burnout to subcooled water are those of Bernath (*50*) and Griffith (*51*) but they have only been tested for a limited amount of experimental data. They include no term to allow for the L/D effect: indeed Bernath has denied its existence (discussion *47*).

The effect of the L/D ratio on the burnout heat flux is a factor which needs careful study as to the mechanism involved. Burnout is essentially a local phenomenon and one would expect it to be determined solely by the conditions at the point of burnout and thus to be independent of the length of the tube. However, it was found that the burnout heat flux for the same local fluid conditions at the point of burnout was more than halved by increasing the L/D ratio from about 65 to 300 (*44*). This reduction of the burnout heat flux imposes a limitation on pressurized water reactor design.

Two possible explanations of the effect are put forward here: 'bubble sliding' and instability. In the former explanation, which on the face of it appears less likely, it is suggested that bubbles formed upstream slide along the tube wall to the burnout point causing the blanketing of the heated surface (or possibly a change in flow pattern in bulk boiling) at a lower heat flux than would otherwise have been obtained. This bubble sliding has, in fact, been observed in subcooled water (*5*) but considering the small size of the bubbles, one would expect that if this were the true explanation, the relaxation length for the L/D effect would be, at most, a few bubble diameters. The burnout heat flux should then be unchanged for lengths greater than an inch or two instead of still varying after two feet.

Alternatively, flow instability may account for the observed results. If burnout were immediately preceded by a sudden reduction in flow, resulting from the way in which the vapour was being formed, burnout would atually take place at a lower flowrate than the measuring instruments indicated. Although this effect was looked for without success (*39*), its detection would be dependent upon instrument response time. If the reduction in flow took place too rapidly to be detected, this might be the reason for the L/D effect. Thus, in a heat transfer loop containing a constant-head pump and test section and with the flow controlled by a throttle valve, the pressure drop across the test section for a given flowrate would be a greater proportion of the whole if a long narrow tube were used rather than a short wide one and the system would thus be potentially less stable. The reduction in flow would be correspondingly greater as the L/D ratio was increased and burnout would occur at a lower heat flux.

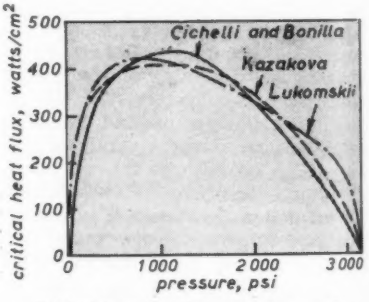
Consideration of the experimental evidence (*45*) gives no indication which—if indeed either—of the two explanations is correct. In addition, since only a limited range of diameters was taken there is very little evidence that the effect was due to L/D rather than L alone. A better understanding of this phenomenon, leading to methods of raising the burnout heat flux for long channels, would be valuable in reactor design.

It must be emphasized that burnout, not critical, heat flux was measured in the experiments (*45*), although the general conclusions reached are not thereby invalidated. Results were obtained using a burnout detector, a device for saving the test section by cutting the electrical power just prior to actual rupture. This, although giving conservative estimates of the critical heat flux, would inevitably add to the error and scatter in the results. In later experiments the detector was arranged to operate before the critical heat flux was reached, at the upper end of the nucleate boiling regime (*52*) (i.e. point C in figure 7).

Empirical relation only

These burnout correlations for water flowing in vertical channels are purely empirical and for that reason their usefulness is limited to the set of conditions from which they were obtained. As far as the present trend of reactor design is concerned, they are valuable because the experiments formed part of a reactor programme and hence the geometry and operating conditions are particularly relevant. There is, however, a very great need to obtain a sounder theoretical basis for the burnout correlations. For operation with different fluids, e.g. organic liquids, or for very different geometries, the empirical Westinghouse correlations would not be applicable.

Pool boiling results are more readily adapted to providing a theoretical basis because of the comparative ease with which the operating conditions can be changed and observed. In pool boiling experiments at saturation temperature, the critical



Critical heat flux in saturation pool boiling reaches a maximum at about ⅓ of the critical pressure (Fig 14)

heat flux for water and a number of organic liquids has been found to vary with pressure, reaching a maximum in all cases at approximately one-third of the critical pressure. Cichelli and Bonilla (*53*) found that, plotting maximum heat flux divided by critical pressure against reduced pressure, a single curve correlated the experimental data for a variety of organic liquids. Later work by Kazakova (*54*) and Lukomskii (*55*) showed that virtually the same curve may be used to correlate water data as well. This is illustrated in figure 14 where

the results of the two Russian workers are compared with the values calculated for water from the correlation of Cichelli and Bonilla. A similar variation of critical heat flux with pressure has also been found for water flowing in vertical channels (*33, 45*).

Various empirical correlations of burnout data obtained from pool boiling results have been proposed. Perhaps one of the more successful of these, and applicable to a variety of organic liquids as well as to water, is that of Rohsenow and Griffith (*56*). Their correlation was derived from a semi-theoretical analysis considering bubble diameter and surface coverage, the value of the constants being determined empirically. The equation proposed was

$$\frac{(q/A)_{Bo}}{\lambda\,\rho_v} = 143\left[\frac{\rho_L - \rho_v}{\rho_v}\right]^{0\cdot6}\ \text{ft/h}$$

where $(q/A)_{Bo}$ = burnout heat flux, λ = latent heat, and ρ_L, ρ_v = densities of liquid and vapour.

This correlation was extended by Griffith (*51*), to take into account the effect of velocity and subcooling. The final equation obtained was comparatively complicated and contained a sum of terms in velocity, subcooling, and a product of the two.

Theoretical approach

A correlation, similar in form to that of Griffith, was developed by Zuber and Tribus (*13*) from a purely theoretical approach. Taking as their model the concept, already described, of vapour columns rising from the heated surface with down-jets of liquid between, they analysed the hydrodynamic stability of the interface between the liquid and vapour. A critical wavelength was obtained corresponding to the break-up of the vapour columns into drops, i.e. to the change from transition-film to nucleate boiling. Tacitly assuming that this took place at the critical heat flux (i.e. at D rather than C in figure 7), they obtained correlations for the cases of both saturation temperature pool boiling and subcooled pipe-flow. The final equation for the former case was similar to one proposed previously by Kutateladze (*57*). Although one may disagree with many of the assumptions in the theory as it is put forward, consideration of the hydrodynamic stability of the system would appear to be a fruitful approach to the problem.

For predicting the burnout heat flux in organic liquid-cooled reactors the only general correlation available at present is the one of Griffith (*51*). This was based upon data obtained for water, benzene, heptane, and pentane; its overall accuracy was ±33%. As a design equation it should be used with caution since in determining the empirical constants some of the lowest burnout values were discarded because of suspected instability or for other reasons. No allowance was made for any L/D effect which, as previously discussed, may be another manifestation of instability. For polyphenyl liquids, Core and Sato (*58*) tested the correlation for diphenyl and found that the measured values of burnout heat flux were much lower than the predicted values. More accurate empirical correlations for diphenyl and Santowax R, applicable only over a limited range of variables, were suggested:

Diphenyl: $(q/A)_{Bo} = 454\,(T_{sat} - T_b)V^{0\cdot63} + 116{,}000$

Santowax R: $(q/A)_{Bo} = 552\,(T_{sat} - T_b)V^{0\cdot67} + 152{,}000$

where, as before, $(q/A)_{Bo}$ = burnout heat flux in Btu/ft²h, $(T_{sat}-T_b)$ = the degree of subcooling of the liquid at the point of burnout in °F, V = liquid velocity in ft/s.

Limitation on reactor design

The magnitude of the burnout heat flux may impose a severe limitation on reactor design. In an emergency, such as a power surge or coolant pump failure, the maximum 'scram-delay time' before safety rods or some other device must shut the reactor down may be largely determined by the burnout heat flux. After shut-down, the heat flux from fission product decay must also be taken into account. Many methods of increasing the burnout heat flux, some of which may well have reactor applications, are actively being considered. These include the effect of additives (*59*), finning, or spikes, to change the hydrodynamic stability of the system—the spacing related perhaps to the Zuber critical wave length, transient effects e.g., heat flux pulsing, vibration, and ultrasonics, and centrifugal flow—a burnout heat flux of $54{\cdot}8 \times 10^6$ Btu/ft²h i.e. 1700 watts/cm², has already been obtained by this method (*60*).

A factor which should not be overlooked is the value of g, the gravitational constant. In the theoretical burnout relations of Kutateladze (*57*) and Zuber (*13*), the critical heat flux is proportional to $g^{\frac{1}{4}}$ and although this is of course constant for land based reactors its effect may be significant in a ship reactor, or in rocket applications.

The position with regard to burnout in nuclear reactors may be summarized as follows:

a. The Jens and Lottes, and the Westinghouse equations, are useful for design calculations for pressurized and boiling water reactors as currently envisaged. The correlations are empirical in nature and are therefore only applicable to the set of conditions for which they were determined.

b. A correlation factor has been added to them to allow for the apparent reduction of heat flux with increasing length of heated channel. More work is required to explain why such a geometrical effect should exist and a method may then be found for increasing the burnout heat flux, thus raising the margin of safety in reactors.

c. Other methods for raising the burnout heat flux are currently being investigated.

d. For burnout to other fluids, subcooled and flowing in vertical channels, the only general correlation is that of Griffith. Such a correlation is particularly required for organic liquid cooled reactors. It has not yet been tested for a wide variety of liquids but has been found to be over-optimistic for diphenyl. Consequently, it is not recommended for use with the polyphenyl class of organic coolants for which, over a limited range of variables, the correlations of Core and Sato may be more accurate.

FILM BOILING

Information regarding heat transfer and steam voidage in the transition film and film boiling regimes may be required for nuclear reactor safety considerations. It has been suggested that heat fluxes in excess of the burnout value could be permitted in a PWR, with consequent easing of other design safety limitations, provided that the temperature excursion of the fuel element was small enough to do no damage (*44*). In the event of the burnout heat flux being exceeded, the degree of danger involved, i.e. whether the fuel element would be vaporized, burst or undamaged, would depend upon the effect of steam voidage on reactivity and the proportion of the heat flux still transferred to the water.

At present, no precise experimental data are available which can be regarded as being directly applicable, except perhaps for the BORAX (*61*) experiments, some work at atmospheric pressure described by Untermyer (*62*), and the film boiling correlations proposed by Bromley (*63*). In the general case the transients involved can only be calculated by making drastic assumptions and although there have been several attempts (*64, 65*) at this problem none can be regarded as wholly satisfactory.

Acknowledgements and references are on p. 118.

Since the original processes at Springfields were described in Nuclear Power three years ago new plants have been built covering the whole process of fuel element manufacture

Fuel element manufacture at the U.K.A.E.A. factory

by JOHN WOODESON BSc(Eng)
Deputy Editor, NUCLEAR POWER

IN A NUTSHELL

Raw material	U-ore concentrate
Products	(1) uranium hexafluoride (2) natural uranium fuel elements
Cost	Original plant £M5½ New plant £M12
Present size	Area 218 acres Employees 2750
Output of fuel elements	1 million to Feb '59
Dates	First rods produced Feb 1948 TBP plant completed July 1956 Switch magnesium reduction April 1957 New machine shop commissioned June 1958 No 1 new canning line completed Feb 1959

IT IS JUST ten years since the production of the first uranium rod at the Atomic Energy Authority's Springfields plant marked the real beginning of Britain's nuclear energy programme. Since then the original plant, hurriedly constructed for batch processes scaled straight up from the laboratory, has worked amazingly well, fulfilling its double function of producing uranium hexafluoride for enrichment at the Capenhurst diffusion plant and making all the natural uranium fuel elements used in the reactor programme. However its replacement was only a matter of time. Plants more suitable for continuous production are now being completed, and NUCLEAR POWER was recently invited to go over them in the first press visit ever held at Springfields. The new plants will cover all stages of fuel element manufacture for the AEA and Central Electricity Generating Board plants, as well as providing for any future export orders, and as they are finished the original plants will be gradually taken out of commission. No new plant for hexafluoride production is contemplated. Future plans for Springfields include research on canning with new materials such as beryllium and work with slightly enriched uranium ($2C_o$ material is already being used).

CONCENTRATE TO TETRAFLUORIDE

The first stages in the new process have been simplified by using concentrate (containing 60–70% uranium oxide) from which the mined impurities and any valuable materials (e.g. radium) have been removed. This has replaced pitchblende as the raw material and special gamma protective measures against radon are no longer needed. It is sent from Canada, Australia and South Africa in drums as powder—though the South African particle size is much larger than the other two—and delivered to the ore storage area at the north end of the plant. If at any time the starting material changes, the AEA plans to give it a separate pretreatment to convert it to the approximate composition of the concentrate.

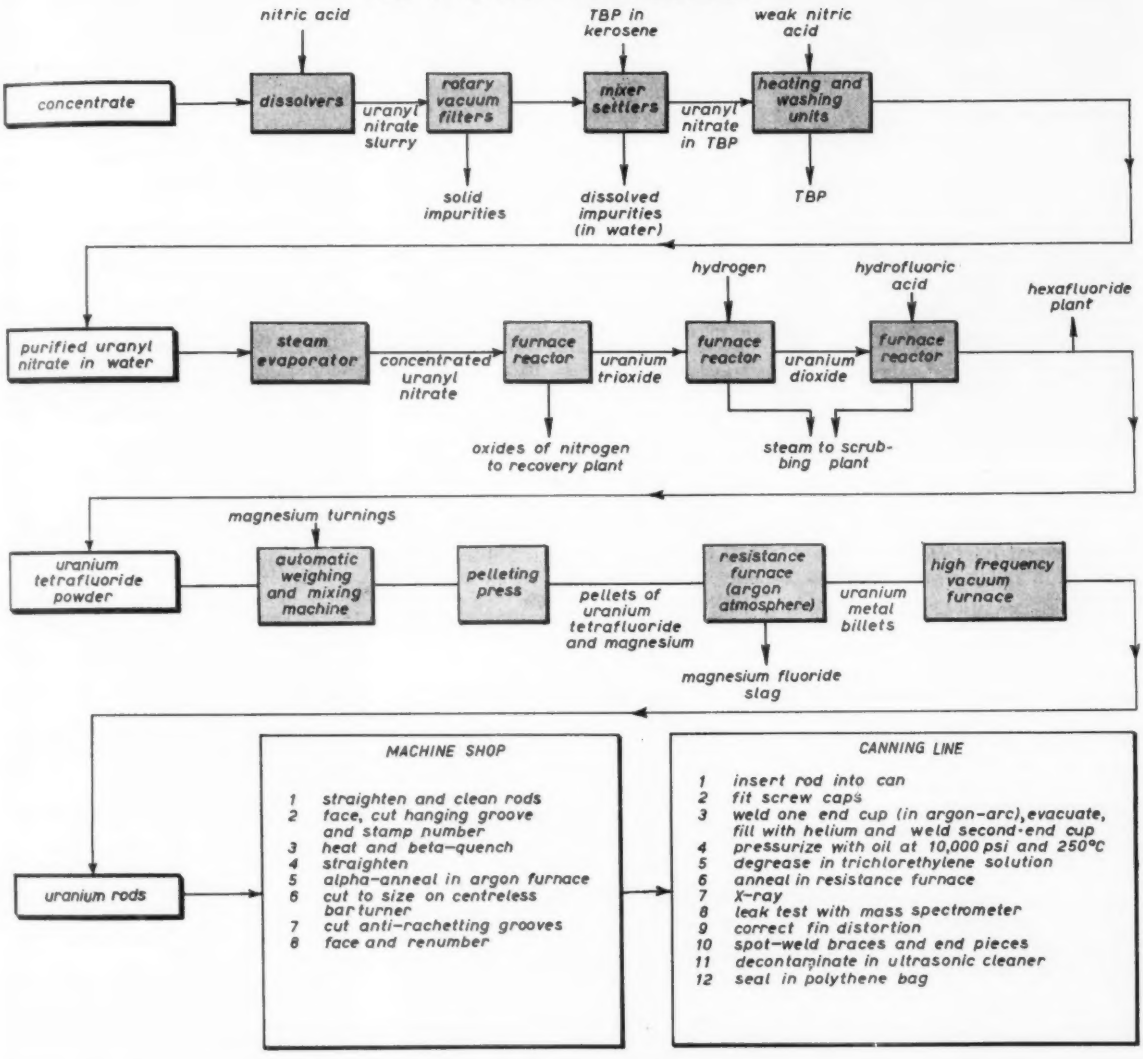
When required the drums are taken up by lift to the tipping area. Some are sampled by removing the lids and bringing them up under a static sampling tube which bores through the concentrate, the number thus sampled depending on the Authority's contract with the supplier. The drums then pass into a totally enclosed tipping cubicle where the concentrate is poured into a hopper with a screw feed to the dissolvers on the floor below. It is manned by a single operator using two levers: one moves the drum over the hopper and the other controls the tilting. Air is continuously extracted from the cubicle and passed through the filter system so that the amount of dust which could escape when the door is opened is kept to a minimum.

In these mixer-settler tanks the uranyl nitrate dissolves in the TBP solvent while the impurities remain in the aqueous solution

Nitrate purification

In the dissolvers—large stainless steel tanks fitted with steam heating coils and stirrers—the concentrate is dissolved in nitric acid, and the solution, after cooling, is fed to Stockdale Engineering Co rotary filters. These consist of large rotating horizontal drums of fine mesh continuously evacuated from the inside. The lowest part of the drum dips into the slurry from the dissolvers and the solution of uranyl nitrate is sucked through the mesh while the solid impurities are collected on it and then continuously scraped off on a knife edge, forming a cake which consists mostly of silica. This is reslurried and passed to a

THE FINAL FLOWSHEET



THE ORIGINAL PROCESSES

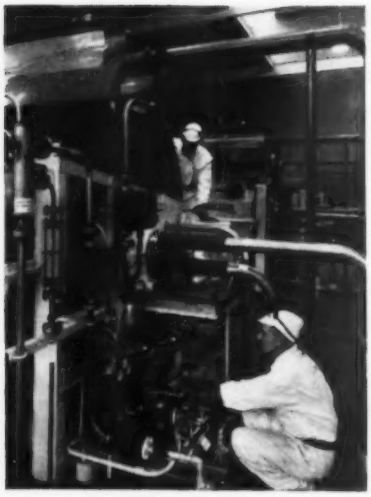
● **Pitchblende to oxide** The ore was tipped into crushers remotely and then converted to a slurry by mixing with water in a ball mill. The slurry was fed to a heated stainless steel tank along with nitric and sulphuric acid which dissolved the uranium and left the bulk of the impurities—including the radium—in suspension. After pumping through filters the uranium was precipitated as a crude peroxide on filter presses by the addition of hydrogen peroxide.

● **Oxide to pure nitrate** The peroxide was redissolved in warm nitric acid, evaporated under reduced pressure until it reached the composition of uranyl nitrate hexahydrate, filtered through fine gauze and purified by a single stage solvent extraction process using ether.

● **Nitrate to tetrafluoride** Addition of ammonia precipitated ammonium diuranate, which was filtered and stacked in trays for conversion into tetrafluoride in one of the 54 furnaces of the Dryway plant.

● **Tetrafluoride to metal** Calcium chips were added to drums of tetrafluoride in an enclosed cabinet and the contents mixed under an argon blanket by rumbling the drum before loading into a crucible lined with calcium fluoride. The crucible was sealed in a firing chamber and the reaction initiated by dropping in an ignited pellet of potassium nitrate and lactose mixture. Sufficient heat was generated to melt the uranium produced, which sank into a cavity, forming a cylindrical billet, with a thick layer of calcium fluoride slag on top. Casting of rods was carried out in bottom pouring high frequency vacuum furnaces of the stationary crucible type. Elements for the now finished Windscale reactors were made in this way and also those for Calder Hall and Chapelcross.

● **Canning plant (still operating)** This is not laid out as a continuous line; for example the welding installations (semi-automatic) and evacuation and helium filling devices are separate. The sequence is: first screw cap fitted, one end cup welded, bar inserted, second cap fitted, element evacuated and filled with helium, second end cup welded. The element is pressurized in an autoclave under carbon dioxide at 350 psi and 500°C, and leak tested with a mass spectrometer; cleaning and correction of fin distortion is carried out in a small rotating brush machine fitted with a steel comb.



The concentrate is dissolved in nitric acid in stainless steel tanks fitted with heating coils and stirrers

second similar filter to ensure that all traces of uranium are removed, and then dumped.

The uranyl nitrate solution then contains only dissolved impurities, which are removed by solvent extraction with a solution of tributyl phosphate (TBP) in odourless kerosene in 16 mixer-settler tanks arranged in cascade. As this part of the process is fully automatic the units are placed in the open. After mixing in the tanks the water with dissolved impurities settles below the TBP solvent, but because of its greater solubility in TBP, the uranyl nitrate collects in the solvent phase on top. From a settler section the solvent flows forwards to the next mixer unit while the water and impurities drain back to the previous mixer section. In this way the uranyl nitrate can be almost completely removed from the aqueous phase. At the top of the plant the TBP emerges containing the uranyl nitrate in solution, passes through a heating unit, and the uranyl nitrate is washed out of the solvent by a weak nitric acid solution and pumped to storage tanks.

Conversion to tetrafluoride

This part of the plant, still under construction, will employ fluidized bed methods, replacing the old 'Dryway' plant (*1*), which works from ammonium diuranate precipitated by adding ammonia to the uranyl nitrate. By using nitrate direct, and cutting out the diuranate, which has to be hand loaded on to graphite trays for the furnaces, the new plant will be much more suitable for continuous large-scale production. Uranyl nitrate will be boiled by means of steam in an evaporator to reduce it to a thick syrupy concentrate and sprayed into the first of three interconnected furnace reactors. In the first it will be heated and decomposed to uranium trioxide, in the second hydrogen will reduce the trioxide to dioxide, and in the third hydrofluoric acid will react with the dioxide to give uranium tetrafluoride powder. In the Dryway plant diuranate is converted to trioxide, dioxide and tetrafluoride in the same reactor, which has a series of connexions to the hydrogen and hydrofluoric acid supplies. Various oxides of nitrogen will be produced with the uranium trioxide in the fluidized bed plant, and nitric acid will be recovered for re-use by means of a large fume absorption unit. Manufactured by Burnett and Rolfe under subcontract from Kellogg International, it includes six 40 ft high 6 ft dia stainless steel absorption towers packed with ceramic rashig rings, which with associated coolers and condensers occupies an area of about 1500 sq ft. In the second and third furnaces contaminated water vapour produced will be passed through filters and scrubbing units before release.

REDUCTION TO METAL

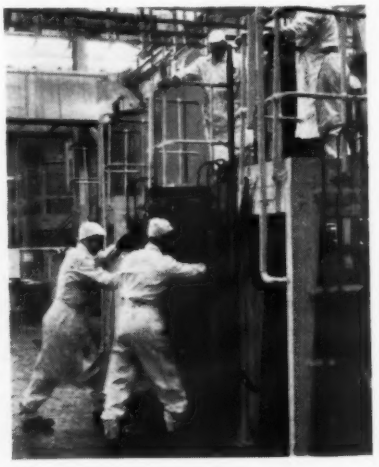
To remove the fluoride atoms magnesium turnings are now used — a cheaper reducing agent than the calcium of the original process(*1*), though considerable development work was necessary before the present technique was perfected. The uranium tetrafluoride powder and magnesium turnings are delivered from overhead storage hoppers by gravity to an AEA-designed automatic weighing and mixing installation built by George Driver & Son and William Gardner & Son (Gloucester) respectively. The mixed constituents pass down a chute to a Fielding and Platt pelletting press—also automatic—which is synchronized with the mixing machine and ejects the 3 kg pellets on to a transfer mechanism. This marshalls them into groups and discharges them to a conveyor moving to the reduction plant.

When the reaction has taken place, reducing the magnesium and uranium tetrafluoride to a uranium billet and slag, the reactor is lifted from the furnace and moved to the cooling bay on the right

Here they are stacked inside graphite sleeves in a stainless steel furnace reactor measuring about 12 ft long × 3 ft dia. This is moved into the adjacent furnace bay and lowered into one of the General Electric Co resistance furnaces in which the reduction reaction takes place in argon at atmospheric pressure to produce molten uranium and magnesium fluoride slag. Each furnace is equipped with a Honeywell temperature recorder and the maximum value reached is about 925° C. From the furnace the red-hot reactor is carried by a 5-ton gantry crane to the nearby cooling bay and lowered into one of the chambers. After cooling the reactor is brought back, dismantled, and the slag, together with the uranium billet in the catchpot at the bottom, are removed. The 200 kg billets, about 9 in. long and 10 in. dia, are sent to a cleaning section, and then sampled and numbered.

Vacuum casting

The first step in making fuel elements is to melt the uranium billets and cast them into rods of the required size. This is carried out in one of 8 Metro-Vick high-frequency induction furnaces, arranged in two lines each supplied by 150 kW motor-generator set. The temperature is recorded on Kent instruments with



An assembly of moulds is moved into one of the vacuum casting furnaces used to melt the billets

a maximum reading of 1600° C in front of each furnace. The 500 kg charge, made up of billets plus pieces of previous casting headers and rejected rods, is packed in a graphite crucible for placing in the furnace; a water-cooled vacuum bell is fitted on top and the casting is carried out under fairly high vacuum to avoid solid and gaseous impurities in the cast. The method used is to pour a complete melt at once by removing a spigot in the base of the furnace; the metal then runs into a graphite header

In the machine shop a uranium rod is removed from the beta quench apparatus

which feeds a cylindrical assembly of graphite-lined, stainless steel moulds mounted on a bogie. About 30 moulds are used, but the exact number depends on the length of fuel element required. The mould assembly is wheeled out, cooled and dismantled, and the rods taken into a bond store, each cast being kept separate. The crucibles are prepared for re-use by means of a cleaning furnace (Metalectric Furnaces).

MACHINING THE RODS

The main problems in machining are the length of the rods (up to 42 in.) and the tendency of the grain to grow (2); straightening operations are therefore included as well as heat treatment designed to produce a satisfactory metallurgical condition to minimize distortion during irradiation. This is, broadly, a small randomly orientated grain size. Conventional machine tools like standard lathes or centreless turners are used, the only special precautions being the provision of an exhaust system away from the operator, and a copious supply of coolant to prevent the swarf igniting and to minimize the risk of particles escaping into the atmosphere. The turnings are collected, cleaned and added to subsequent casting charges.

The first machine, a Farmer Norton reeler, straightens and cleans the rods before passing them to a specially-designed BSA Hüller machine which faces the rods to slightly more than the required length, cuts a hanging groove near one end for support in later operations and stamps on a serial number. The sequence is semi-automatic at present but the Authority intends to develop full automatic operation with pickups transferring the rods from the first to the second machine and then to a Paterson Hughes overhead conveyor. This takes them to the top of a beta-quench apparatus designed in conjunction with A. C. Wilson Ltd, where they are fed vertically downwards one at a time through three 10 kc/s heating coils supplied by one 150 kW generator; below these is a force-fed water quench spray and the rods are finally removed from a water-filled tank at the bottom of the apparatus. A variable speed motor is used for the upper draw rollers to keep the rods in end-to-end contact during their passage through the coils and avoid end overheating.

Any warping of the rods is corrected in another reeler, and the grain size is further reduced by alpha annealing in a bank of 14 Birlec 80 kW vertical resistance furnaces. 30 rods at a time are assembled in a jig—suspended from a roof rail—in which they are supported by the hanging grooves, and lowered into a container. This is evacuated and filled with argon before heating in one of the furnaces, where the temperature is held at 550° C for 1 hour. They are cooled under controlled conditions, and at this point samples are micropolished for checking the grain size.

Actual machining to the required dimensions (1·150 ± ·001 in. dia for Calder Hall) is carried out on a Farmer Norton centreless bar turner; about 0·040 in. is removed in each cut and a continuous conveyor is included to carry away the swarf. The rods are then fed to a completely enclosed Fairey automatic anti-rachetting machine which can cut four grooves simultaneously in each rod by means of a multi-tool box plunge feeding from an overhead slide. When the can is later pressurized onto the rods these grooves fix the relative positions and stop the can working off the end of the rod on successive thermal expansions. After sorting the rods are sent through a second facing and numbering machine.

ASSEMBLING THE FUEL ELEMENT

Four lines will eventually be built in the new fabrication plant. No 1, for the Calder and Chapelcross reactors, is now complete and No 2, for development work, and 3 and 4 for the Bradwell and Berkeley CEGB stations, will be ready by the end of this year. The Magnox Calder-type finned cans are made by Fairey's and Armstrong Whitworth's where they are now manufactured by thread-rolling instead of machining as in the past.

The rods are straightened and cleaned on the reeler in the foreground and passed to a specially designed machine behind. This cuts the rod to slightly more than required length, cuts a hanging groove and stamps a serial number

In the canning plant they are first cleaned in a trichlorethylene tank, then examined and comprehensively gauged before sending to the first section of the 250–300 yard line, which consists of a continuous Teleflex con-

An assembly of thirty rods is placed into a container before alpha annealing in a resistance furnace

veyor assembled by Langham Engineering. Because of the importance of avoiding any surface contamination of the can by particles of uranium the bars are not allowed in the shop, but are fed into the cans on the conveyor through a hole in the wall.

The inner caps—machined to give a fixed clearance with the uranium bar—are screwed in and the element moved to two argon arc installations designed by the Authority and made by Newburgh Engineering for welding on the end caps. These, unlike the apparatus on the old canning line, are completely automatic — including the electrode setting for successive passes —and the gun revolves instead of the electrode. The whole sequence in this part of the plant differs from that used in the old line, which was: 1 screw cap fitted, 1 end cup welded, bar inserted, second screw cap fitted, transportation to an evacuation and helium filler set up and second end cup welded. The first of the new welding machines includes it own helium filling apparatus built to AEA designs by Langham Engineering and Barracloughs Ltd; the elements, hung from a pair of rollers which move on a continuous rail, are passed under this and the top screw cap is loosened by a tongue with two pegs which fits into holes in the cap. The can is then evacuated, about 8 cc of helium at N.T.P. are injected and the cap is tightened up again before the rod moves along the rail into the welding chamber.

Pressurizing the elements

The next stage is to squeeze the can firmly onto the rod to ensure good heat transfer and here pressurizing under carbon dioxide at 350 psi and 500°C in an Electric Resistance Furnace Co autoclave has given way to a hydraulic machine developed for the AEA by Foster Yates and Thom which uses oil at 250°C and applies a pressure of 10,000 psi. The plant consists of six pressurizing chambers, each 30 ft long with a bore of 3 in., which are operated as two groups of three, each with its own pumping and intensifying system, heating and control arrangements and hot oil supply. The chambers are surrounded by jackets which are oil heated by means of electric ring elements, 90 per chamber, and the sequence of operation is as follows:

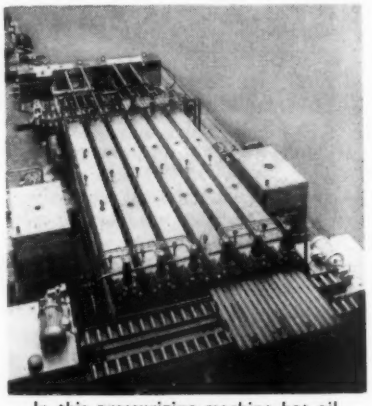
Magazines, in the form of racks holding up to 15 elements loaded side by side, are placed on the loading side roller conveyor. A system of chains and dogs ensures that the magazines are correctly located in front of the various pressurizing chambers; a hydraulic pusher head is brought into operation and three fingers attached to the cross head push three components into their chambers. The magazines are moved forward one pitch and a further three components loaded, the process being repeated until five elements have been placed in each chamber. These are then sealed and hot oil is fed to the inside to build the pressure up to the desired maximum, which is maintained for up to fifteen minutes. After this period the vessels are decompressed and the hot oil allowed to return to the supply tanks. The chambers are opened and the components pushed out (by untreated components being pushed in at the loading end) on to a further set of magazines placed in position to receive them. The loaded magazines are brought to the end of the conveyor, lifted on to trollies and carried to a trichlorethylene de-greasing tank.

Testing

Annealing at 400°C in one of two Metalectric Furnaces resistance heaters follows and the elements are checked in an Authority-designed X-ray machine employing Newton Victor apparatus. It can take a complete view in one shot instead of the three which were previously necessary to cover the whole circumference. For leak testing (at 10^{-5} cm Hg) the elements are mounted in two rigs which can carry up to 12 each and are arranged for sequential sampling by a Metro-Vick mass spectrometer calibrated for helium leakage. Distortion of the fins caused by the pressurizer is corrected in a small machine which employs two rotating disks spaced one fin pitch apart, and the end pieces and braces are spot welded on. Braces are now made in three parts to take up any variation in fin pitch, because the rolling technique used for making the cans has not yet reached the accuracy of the machining previously employed.

Decontamination

The final operation is decontamination in an ultrasonic washing unit developed and made for the Authority by G. Hopkins and Sons which supersedes the simple rotating brush machine (combined with a comb for fin straightening) used in the old plant. It consists of three sections, washing, rinsing and drying, and after being loaded horizontally on to carriers at one end—hand or automatic loading can be used—the elements are moved by a conveyor right through the machine at an adjustable rate of about 60 an hour. Each carrier supports five elements symmetrically spaced on a circle of 5½ ins. dia and rotates continuously to allow each element to be cleaned round its entire periphery. This rotation also avoids the possibility of the elements bending under their own weight at the temperatures involved. The washing section is a stainless steel bath into which citric acid solution is continuously fed at a rate and strength (usually about 1½%) controlled by Rotameter flowmeters,



In this pressurizing machine hot oil is used to squeeze the cans firmly on to the rods

the spent solution overflowing by means of a weir. As the elements move through the tank they spend 5–6 minutes over a bank of four Mullard 20 kc/s nickel magnetostrictive transducers powered by a 2 kW generator which create the ultrasonic cleaning field to give a decontamination of the order of 1 mg of foreign matter per ft length of element. The final operations on the Calder elements are: washing, drying in hot air, sealing in polythene bags and packing three to a box.

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Britain lags in industrial applications of isotopes owing to the present obscure legal position. Urgent action is called for in this report by a special correspondent in industry

Isotopes and the Factory Regulations

AFTER TEN YEARS' industrial experience with radioisotopes, the United States Atomic Energy Commission estimated that American factories were saving about $M500 a year through the use of tracer techniques, nucleonic thickness gauges, level gauges, density gauges, gamma radiography, etc.

Some of Britain's scientists and engineers, justly proud of our position as a producer and exporter of radioisotopes, have been prompted by these American claims to try to take stock of the situation in British industry. While it is practically impossible to obtain any accurate assessment of the economies achieved by the use of isotopes, it is generally felt that progress has been disappointing. There may be many reasons for this, but one is the uncertainty of the legal position of industrial isotope users.

The big questions

When radiation thickness gauges and other similar techniques were introduced to British industry some ten years ago, among the first questions asked by the average works manager or works engineer were: 'Is it safe to handle?'—'Is there any danger to workers who stand near this gauge when it is operating?'—'Will it make the factory products radioactive?'—'Does it conform with existing Factory Safety Regulation?'—'Where can I get reliable and authoritative answers to all my questions?'.

These queries were generally addressed to members of Harwell Isotope Division, to factory inspectors, or to nucleonic instrument makers. In the early days the questioner would usually be referred to recommendations laid down by the Medical Research Council for the guidance of hospital staff and medical research workers. Later, came recommendations of the International Committee for Radiological Protection, and an advisory service set up by the Radiological Protection Service of the Ministry of Health and MRC. Throughout the whole period the Factory Inspectorate of the Ministry of Labour and National Service have been most helpful. Its experts have always been ready to visit individual factories for discussions, and to give advice on the safe installation of radioactive sources. It has also issued a booklet giving in general terms a code of practice for the safe use of ionizing radiations in industry. Nucleonic instrument makers have, on their part, endeavoured to design equipment for maximum safety under practical conditions of use, and have carefully studied current recommendations.

Desire for rules

Despite all this advice, there was still reluctance on the part of a few industrial managers to accept radioactivity under their roof. This was firstly because the advice was frequently worded in terms they could not understand, terms often related more directly to laboratory tracer techniques, and having little practical relevance to the safety of installed radiation gauges. Secondly there was the feeling that advice and recommendations were not enough. There must be well defined regulations, preferably incorporated into the Factory Act, by which a definite decision could be made as to whether a nucleonic instrument would be acceptable or not from the safety point of view. This desire for a clear set of rules was expressed by users and suppliers alike. For the suppliers felt that this would give them a secure basis on which to answer the doubts of potential users, while industrial management felt that they in turn could answer with good authority doubts expressed by their workers, by saying in effect, 'This installation complies with the appropriate Factory Safety Regulations.'

Thus, about 1956 there was considerable satisfaction with the news that Factory Regulations were in the course of preparation. The special Regulations appeared in the form of a Preliminary Draft dated 1957 which was published by HM Stationery Office so that objections and comments could be put forward by all interested parties for consideration before the Regulations were made law. The opening and closing sentences of the draft suggested that it was intended to become law in 1957.

While it was hoped that the provision of Regulations would do much to simplify and, therefore, stimulate the expansion of radioisotope uses in Britain, the publication of this preliminary draft appears, so far, to have had the opposite effect. The fault may lie partly in the draft itself—its form and content. On first reading it through a works manager is apt to decide that he would forgo the benefits of radioisotopes, rather than accept all the conditions attached to their use. In some respects the whole theme of the Regulations may be criticized as having been designed for the protection of specialist workers in the field of radioactivity rather than the protection of ordinary workers in general manufacturing organizations. It might be argued that there is too much emphasis on monitoring and medical examination of personnel, and too little incentive to the instrument maker to produce intrinsically safe apparatus. Some of the most useful nucleonic instruments, thickness gauges, level gauges, and package monitors, require only small shielded sources of low activity, yet they may be used in factory processes employing hundreds of operators and very few specialists. It seems likely that the management would readily pay for additional shielding or guards to be fitted in order to make the equipment completely safe, but would think twice about the provision of special medical examination facilities, film badges or dosimeters for process workers.

Industry sits back

Objection, criticisms and suggestions such as the above are all matters of opinion, and no doubt many have been submitted for consideration. The main trouble with the draft is that it is still only a draft. Having seen it and commented, industry is now sitting back waiting to see how much of it will become law, how the final version will be worded, and how it will be interpreted in practice. Even organizations which in the past would have been prepared to study carefully the current codes of practice, and follow these in order to evaluate the usefulness of some instrument or tracer technique, are now inclined to pursue a policy of 'wait and see.' Therefore, if Britain is to make progress in the exploitation of radioisotopes, some firm regulations are urgently required, and even if these in the first place are over-stringent, they will be better than none at all.

An automatic counter for irradiated foils

by M. F. SMITH *A.E.R.E., Harwell*

SEVERAL SECTIONS in the Reactor Division at AERE Harwell use the foil activation method *(1)* for measuring thermal and epithermal neutron distributions.* The usual technique has been to use several counting channels each connected to a coventional scaling unit and to measure the activity of each foil on all the channels in turn. This necessitates periodically moving the foils from one counting head to another and noting the readings on several scaling units. Besides the wastage of manpower, this system is liable to human errors and only has a limited counting time unless operated on a shift basis.

The Automatics Group of the Electronics Division at AERE were asked to consider the problem and as a result the prototype equipment (Fig 1) was designed by Messrs J. Leng, J. C. Boag and K. E. Parnell. Although a 'one off' design, to suit the requirements of a particular section, it has proved so useful that this article has been written to draw attention to the possibilities and advantages of automation for routine 'counting' of large numbers of foils. The Automatics Group are now designing an improved model which should be able to fulfil wider requirements regarding the size of foils and the type of counting head which can be used.

Before describing the equipment in detail it will be as well to mention how it differs from mechanisms already in existence which automatically 'count' a series of foils under one counting channel.

To improve the statistics of the results without increasing the overall time of count—which is not possible with rapid decay activities—it is necessary to use several counting channels at the same time and to have a means for intercalibration. It is advisable to carry out this intercalibration continually during the time the foils are being counted because of the variability of the counting channel characteristics. This is especially so when alcohol-quenched geiger tubes are used as detectors, as has been customary. This intercalibration can be accomplished either by using several foils in a *Standard* rotation or else by using one foil in a *Monitor* rotation.

A *Monitor* rotation is defined such that there is one foil which is repeatedly counted on each channel in turn, e.g. every fourth foil to be counted on each channel is foil $\underline{M}$: it is preferably one of the foils being investigated. A *Standard* rotation is defined such that there are one or more foils which are each counted once only on every channel. Foils of constant activity are usually chosen in order to eliminate corrections for radioactive decay.

TABLE I *Typical rotation sequence for foils A, B, C . . . on four counting channels using a foil* $\underline{M}$ *in a monitor rotation*

TIME (UNITS FROM ZERO)	CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 4
1	A	—	—	—
2	$\underline{M}$	A	—	—
3	$\overline{B}$	$\underline{M}$	A	—
4	C	$\overline{B}$	$\underline{M}$	A
5	D	C	$\overline{B}$	$\underline{M}$
6	$\underline{M}$	D	C	$\overline{B}$
7	$\overline{E}$	$\underline{M}$	D	C
8	F	$\overline{E}$	$\underline{M}$	D
9	G	F	$\overline{E}$	$\underline{M}$
10	$\underline{M}$	G	F	$\overline{E}$
		etc etc		

N.B. $\underline{M}$ *the foil in a monitor rotation appears on each channel at every fourth count*

It is slightly more difficult to use a monitor rotation than standard rotation but if the foil used is chosen from amongst the irradiated foils being measured it has the advantage that the intercalibration factor is derived for similar radiations, from samples of the same half life at comparable count rates to those of the foils being investigated. Also it allows a check to be made on the dead time of the electronic equipment.

These factors tend to reduce possible errors due to count rate hysteresis and varying energy sensitivity of the counting devices, and also those due to uncertainties in the half-life of the material being irradiated.

It was thus customary to measure the activities or irradiated foils by counting them on from two to four channels following a rotation sequence similar to the form shown in Table I.

Three Operations

The automation of this foil counting process involved three distinct operations.

A. A mechanism to place the foils in turn under different counting heads allowing for the specified form of monitor rotation

B. The printing out of the results from dekatron scaling units (AERE type 1221) onto a paper roll

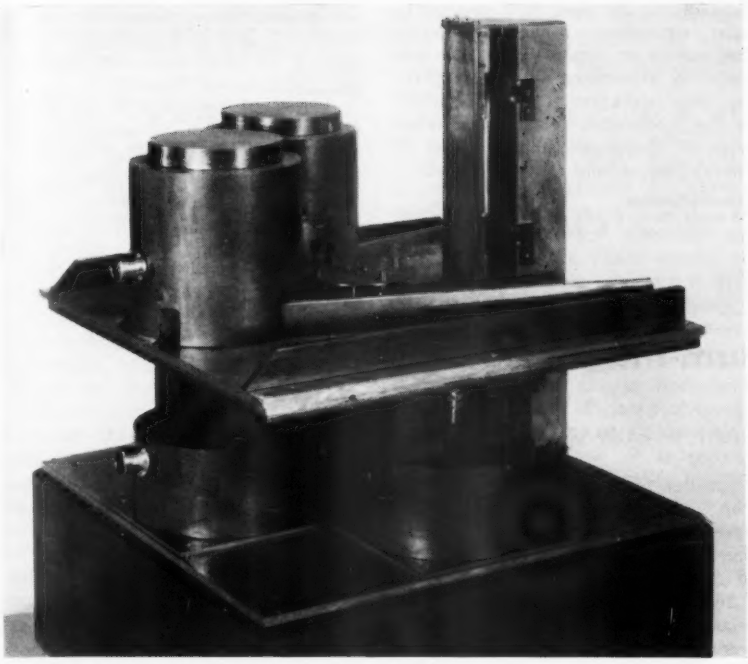
C. A control mechanism to supply time control for the scaling units and to interlate them with operations *A* and *B*.

The foil-changing mechanism consists of a horizontal turntable divided into quadrants. Corresponding to the quadrants are three counting channels and one 'magazine' position where the foils are put on and taken off the turntable. The foils are supported in small rectangular $1\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. synthetic resin-bonded fabric trays which are loaded into the machine by stacking in the magazine. The existing trays will take foils of $\frac{1}{4}$ in. dia. but suitable trays could be made to take foils up to $\frac{3}{4}$ in. dia. These trays with their foils are then accepted one by one onto the turntable which rotates and takes them in turn to each of the counting positions, afterwards returning them to the magazine position where they are rejected from the turntable by being lowered on to a tray stack below the turntable. This four-position turntable therefore provides a means of passing a series of foils through three counting channels.

*for example, when manganese is irradiated in a neutron flux the following reactions take place:

$$Mn^{55} + n \longrightarrow Mn^{56} \xrightarrow{2.58^{h}} Fe^{56} + \beta^{-}$$

Measurement of this rate of beta decay then gives a value of the original neutron flux to which the manganese was exposed.



The partly assembled counting machine shows (nearest) one of the twin geiger tubes at each of the three counting positions. A turntable carries the foils from the magazine (right) to the counters (Fig 1)

It is also possible to lock any of the turntable quadrant positions so that once a tray with its foil has been accepted on to the turntable it will not be discarded. Thus if just one of the turntable positions is locked the mechanism will provide the monitor rotation as shown in Table I, viz on each counting channel every fourth foil counted is foil M. If two opposite turntable positions are locked, a monitor rotation with two foils is provided. If all four positions are locked the same four foils are continually counted in sequence through the three counting channels.

An ordinary Addo model 40E adding machine with the maker's standard modification of solenoid-operated keys was used for the print-out unit. This gives a compact presentation in a form suitable for direct calculation without any transcription (Fig 2).

Forward or reverse

Two types of operation, manual and automatic, can be selected. When on the manual setting, toggle keys control the operation (start, stop, and reset) of the scaling units, the turntable position and the printing out from the scaling units. When on the automatic setting the control mechanism is operated from half-minute pulses supplied by a standard clock. It is then arranged that the foils can be counted for periods of either two or five minutes with intervals of one minute between successive periods, the counting periods commencing every three or six minutes respectively. Once having counted all the foils the machine will either switch itself off or reverse so that it recounts all the foils, but this time in the reverse order as it accepts them from underneath the turntable and restacks them in the magazine above.

Halogen-quenched tubes

On this particular machine the counting heads are each composed of two Mullard Type MX 123 end-window halogen-quenched geiger tubes arranged above and below the turntable so that radiations from both sides of the foil are detected. Previously alcohol-quenched tubes had been used but it was decided to change to halogen-quenched counters in view of their improved stability, lower working volt age, and longer life.

To date this machine has been used at Harwell for measurements in conjunction with the homogeneous aqueous zero energy reactor HAZEL *(2)* and has amply demonstrated the advantages of automation when applied to the determination of neutron flux distributions by foil activation, as it has enabled the amount of work done in a given time to be doubled with fewer staff than before. The results obtained have also been much more comprehensive and reliable. The foil positioning between the geiger counters was quite adequate to ensure that no greater errors were introduced than those due to the statistical spread on the random radioactive decay.

In view of the volume of results which were being obtained a programme *(3)* was written for their analysis using the Hollerith 555 Punched Card Calculator. This corrected the observed activities for electronic dead time, background activity, radioactive decay, and then calculated the mean result for each foil in each counting channel. A separate punched card is needed for each measured counting rate.

The time spent on analysis of results would be reduced if a means of tray identification was incorporated whereby the tray number was printed out in the space provided next to the appropriate count, and also if either the absolute time or the time from an arbitrary zero was printed out on the paper strip. These improvements are being considered in the design of the improved machine.

A weak link in the chain of automation is that the results have to be manually transposed from the printed paper roll to punched cards and for future work it is intended that the card punch should be coupled directly onto the output from the scaling units.

A more advanced and comprehen-

```
1 0 0 0 7 3 3 0 2
2 0 0 0 7 3 6 2 4
3 9 9 0 7 0 8 5 3 -

1 0 0 0 0 0 0 0 9 8
2 0 0 0 7 1 1 9 6
3 0 0 0 6 9 4 6 4

1 9 9 0 6 9 2 4 5 -
2 0 0 0 0 0 0 8 9
3 0 0 0 6 6 1 4 8

1 0 0 0 0 0 1 0 0
2 9 9 0 6 6 6 3 6 -
3 0 0 0 0 0 0 7 2

1 0 0 0 0 0 1 0 7
2 0 0 0 0 0 0 7 6
3 9 9 0 6 2 7 2 6 -

1 0 0 0 0 0 0 9 5
2 0 0 0 0 0 0 7 9
3 9 9 0 6 1 0 4 4 - ◁

1 0 0 0 0 0 0 9 2
2 9 9 0 6 1 0 9 1 -
3 0 0 0 0 0 0 7 2 ◁

1 9 9 0 5 9 7 2 7 -
2 0 0 0 0 0 0 8 3
3 0 0 0 5 6 6 2 1 ◁

1 0 0 0 0 0 0 8 6
2 0 0 0 5 7 2 0 2
3 0 0 0 5 5 8 6 1 ◁
```

Sample of results as printed on paper roll. Each group of three lines represents counts taken at the same time. The first column gives the number of the counting channel. The second and third columns are available for the foil number but at the moment only print 00 or else indicate the monitor foil by printing 99. The fourth column is spare. Columns five to nine give the count on the appropriate scaling unit. The tenth column gives an additional indication of the monitor foil by marking it with a dash. A triangle is also printed in this column to indicate when the mechanism is running in the reverse direction (Fig. 2)

sive programme *(4)* is being devised for the analysis of foil activation measurements using a Ferranti Mercury computer with punched tape input. If it is possible to employ this programme in conjunction with future automatic equipments there may be advantages in using it instead of the existing punched card programme.

Geiger counters were chosen as the detectors to be used with this particular equipment because, although they are by no means ideal, there was plenty of experience available regarding their operation. The construction of the mechanism is such that other types of detectors could be fitted as alternatives, should they be desired.

Acknowledgements

I would like to express my thanks to Mr G. H. Moss and Mr M. C. B. Russell and to all members of their Automatics Group in the Electronics Division of AERE, Harwell, for their hard work and original ideas which produced this equipment and to my colleagues in the Reactor Division, in particular Mr W. G. Clarke, for many encouraging discussions.

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Nuclear Technology | Materials

Analysis of thorium-magnesium binary alloys

by G. W. C. MILNER *and* J. W. EDWARDS *A.E.R.E., Harwell*

METHODS were required for the analysis of binary alloys of magnesium and thorium containing up to 10 atoms per cent of thorium (51% by weight). The determination of thorium in the presence of magnesium presents no difficulty, since the EDTA titration of thorium using any one of several indicators has been shown to suffer no interference from magnesium.

Magnesium is also best determined volumetrically with EDTA using 0–0′ dihydroxy-azo dyes as indicators. Thorium, however, in even the smallest amounts, masks these indicators and no means are at present available to prevent this interference.

Since the stability constants of the thorium-EDTA and magnesium-EDTA complexes differ by such a large amount (ThY° $pK = 23{\cdot}2$, MgY^{-2} $pK = 8{\cdot}7$), it should be possible to titrate thorium and magnesium consecutively with EDTA and detect the end points by physical methods. Potentiometric titration methods were therefore considered but no great accuracy could be attained.

Attention was next given to the separation of thorium before the titration of magnesium with EDTA. Several methods are possible, but the one adopted was that of precipitation of thorium as its insoluble peroxide.

In the experimental work suitable mixtures of magnesium and thorium were prepared by transferring aliquots of a standard magnesium nitrate solution to 250 ml beakers, followed by the addition of the required amount of a thorium nitrate solution. The volume was adjusted to about 100 ml and the pH to the range 1–1·5 with perchloric acid. Then 1 ml of hydrogen peroxide (30%) was added and the solution heated to between 70 and 80°C for 5 minutes. After cooling to room temperature, the solution was diluted to 200 ml and pH electrodes and stirrer system introduced. The pH was adjusted to 10·3 with sodium hydroxide solution. Then 10 drops of a 0·1% solution of solochrome black 6B in alcohol and 1 drop of a 0·5% tartrazine solution were added and the solution was titrated with a standard EDTA solution, whilst stirring vigorously and maintaining the pH at 10·3. At the end point, which had to be approached slowly, the indicator colour change was from red through grey to pure green. More accurate results could be obtained by adding an excess of EDTA and back titrating to the end point with a standard magnesium solution.

In the analysis of alloys, solution of the sample was obtained in dilute hydrochloric acid with addition of 1–2 drops of hydrofluoric acid (40%) and followed by warming to give a clear solution. The solution was evaporated to dryness after adding 10 ml of perchloric acid (60%) and then diluted to a definite volume in a graduated flask on re-solution of the salts in water.

Analysis of Th-Mg alloys

	COMPOSITION BY ANALYSIS		
SAMPLE NO	Th%	Mg%	TOTAL %
1	38·34	61·54	99·88
2	50·92	49·6	100·52
3	38·56	60·9	99·46
4	45·12	54·7	99·82

The method applied to four typical alloy samples gave these results. The reasonable totals for the complete analysis confirm the suitability in these cases.

This article is a condensed version of UKAEA report No AERE C/R 2527.

Nuclear Technology | Processes

Optimum conditions for vermiculite as an effluent decontaminant

by T. D. WRIGHT *and* J. W. MONAHAN *A.E.R.E., Harwell*

PREVIOUS WORK at Harwell has shown that crude vermiculite possesses properties which render it suitable as a decontaminant for alkaline-active effluent containing high sodium ion concentration. In the Industrial Group's Medium Level Activity Treatment Plant the effluent is subjected to two chemical treatments then passed through columns of vermiculite, the main function of the latter being to remove caesium which is the radioelement most difficult to remove in the first two stages. Vermiculite was chosen as the best of several naturally occurring materials tried. Its advantages lie in its comparatively low cost, reasonable exchange capacity for a naturally occurring material, fairly rapid rate of exchange, flow rates which are still acceptable in alkaline media, and in particular, its affinity for caesium even in the presence of high sodium ion concentrations.

To date (Oct 58) the columns have functioned satisfactorily. In order to estimate the life of the columns used on the plant, several experiments have been carried out on laboratory scale columns. These have shown that when

vermiculite is used to treat a caesium traced solution containing 300 ppm sodium, and at pH 11·5–12·0, breakthrough of caesium occurs after the passage of 200 bed volume ratios of effluent. This is less than was expected. Furthermore, it was evident from breakthrough curves in the alkaline solution that the material recovered an appreciable percentage of its capacity on standing.

Vermiculite is a natural magnesium/calcium or magnesium alumino silicate and the particular batch in use on the Medium Level Plant is mainly in the magnesium form. As a cation exchanger magnesium is therefore the exchangeable ion. It seems reasonable to assume that when it is employed to remove Cs-137 from very alkaline solutions, magnesium hydroxide will be precipitated within the exchange matrix and this is likely to reduce the diffusion speed of cations through the exchanger particles and may impair its efficiency. This has been confirmed by a series of experiments.

On the Medium Plant the chemical stages raise the pH of the effluent to 11·5 and it is at this pH that the effluent is passed through the vermiculite. Thus, although the vermiculite columns are at present performing satisfactorily, the vermiculite is not being used to its best advantage. If the Medium Level Plant should be used as a continuous process it is anticipated that useful life of vermiculite would be very limited under present conditions.

Either of two simple operations would increase the efficiency of vermiculite for plant use as a decontaminant of Cs-137, and it is recommended that: **a.** vermiculite is converted to the sodium form before use by washing with a sodium solution, or **b.** the effluent from the precipitators be neutralized to pH 7·0 prior to introduction to the columns.

Whichever method is adopted the resulting improvement in the performance of the vermiculite should be equal. From the point of view of economics the former is the better pre-treatment since no extra plant is required and neutralization of the effluent to maintain a steady pH would present great difficulties. The sodium chloride solution could be prepared in the columns prior to packing with the absorbent. From the mass distribution coefficient it is evident that once converted to the sodium form vermiculite will decontaminate 1600 times its own volume of effluent, about a quarter of a million gallons per ton of absorbent. The second method would involve the addition of an acid resisting pump and tank to the existing plant.

This article is a condensed version of UKAEA report no. AERE E/R 2707.

Nuclear Technology | Irradiation

X-ray penetration in lead

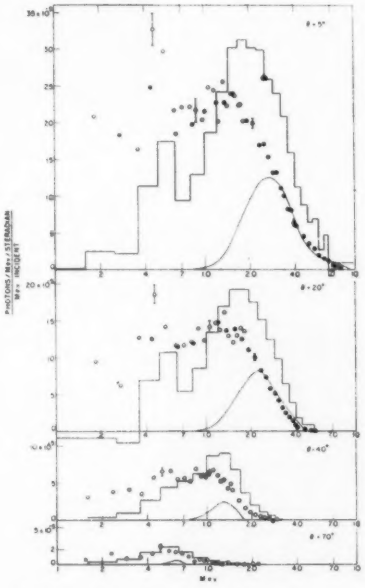
by J. W. HUBBELL, E. HAYWARD *and* W. F. TITUS *National Bureau of Standards, Washington*

THE ENERGY and angular distribution of photons emerging from a lead barrier exposed to 8 and 10 MeV X-rays have been determined by the National Bureau of Standards. The experiment was undertaken to obtain previously unavailable data on transmitted radiation at high energies, and the results not only provide design data for nuclear equipment shielding but also verify the mathematical and computational methods now used in solving penetration problems.

Below 1 MeV some discrepancies were found between the computational and experimental results. As the mathematical theory was designed for an infinite medium, these variations may be due to the presence of a boundary in the experiment. Since good correspondence has been obtained at higher energies, the present study may prove useful in modifying the infinite medium theory to take into account the presence of a boundary.

The 8 and 10 MeV X-rays were *Bremsstrahlung* beams produced in a 50 MeV betatron. Collimated to 9 in., dia the beam was used to irradiate a stack of lead sheets and radiation incident on the plates monitored by an ionization chamber.

Photons emitted by the lead barrier were detected by a scintillation spectrometer consisting of a sodium iodide (thallium-activated) crystal and analysed by a 30-channel p.h.a.



Energy distributions obtained at angles of 5°, 20°, 40° and 70° by bombarding a 6 in. lead barrier with 10 MeV Bremsstrahlung. The solid and open circles represent the experimental pulse height data, and the histograms are obtained by multiplying the pulse height data by an inverse detector-response matrix. The solid curves are the result of a calculation and represent the contribution to be expected from single scattering alone. The errors indicated are statistical

The pulse height distributions produced by the transmitted photons were measured at 0°, 5°, 10°, 20°, 30°, 40°, 50°, 60°, and 70° to the beam direction, using a 6 in. lead barrier irradiated with both 8 and 10 MeV *Bremsstrahlung*.

In order to obtain the energy spectra of transmitted radiation, a matrix inversion of the experimentally measured pulse height data was employed. The spectra of transmitted energy show that photon energies and intensities change with angle and that multiple scattering predominates over single scattering.

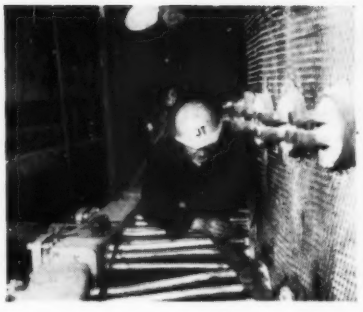
In absolute magnitude and general shape the theoretically-predicted and experimental penetration spectra agree. Except for energies below 300 keV, the experimental numbers are slightly larger than the calculated ones. The secondary processes omitted from the calculation probably account for part of the discrepancy. The higher values in the measured distributions for photon energies above 1 MeV may be attributed to the *Bremsstrahlung* by secondary electrons.

Below 1 MeV the presence of annihilation radiation masks the rest of the distribution. Subtraction of the calculated annihilation radiation component reveals that fewer photons are detected than are predicted by the infinite medium calculations.

Berkeley: a report from the site

1

BERKELEY nuclear power station, begun in January 1957 and due on full commercial load during the winter of 1960–61, is now about half finished. Something like 900,000 cu ft of concrete, 5500 tons of reinforcement and 1600 tons of structural steelwork have gone in, almost completing the civil engineering work, and when NUCLEAR POWER visited the site recently some of the more interesting hardware was already arriving: electrical equipment for the control room, girders for the charge face crane, cranes for the blower houses, the first blower. No 1 reactor building is roofed in and watertight, and the pressure vessel is welded, X-rayed, and almost ready for stress relieving and pressure testing. The AEI-John Thompson Nuclear Energy Co, who are building this 275 MW station for the CEGB, report that they are well satisfied with their decision to eschew a Goliath crane for construction work and intend to follow the same policy in any future nuclear stations.



2

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1. All eight boilers have been erected round No 1 reactor. Five have been glassed in and one is completely tubed. **2.** Most of the high and low pressure evaporators are in place; this l.p. evaporator (left) is about to be attached to its heat exchangers by welding on to the tube headers. **3.** Inside the reactor the 193 bosses for control rods and charge tubes have been welded into the crown of the finished pressure vessel. The next step will be remachining to remedy the distortion due to welding which has pushed some as much as 17 minutes out of the vertical. **4.** Stress relieving of the pressure vessel will follow in March; close up underneath shows the lagging placed round one of the CO_2 inlet ducts. This has been extended round the whole vessel. **5.** The turbine hall behind No 1 and No 2 reactors is finished, six condenser shells are installed and three are being tubed. Circulating water pumps are now being fitted into the Pumphouse to the left of the turbine house and the coffer dam (extreme left) round the cooling water outfall is well under way. **6.** View from the top of No 1 reactor

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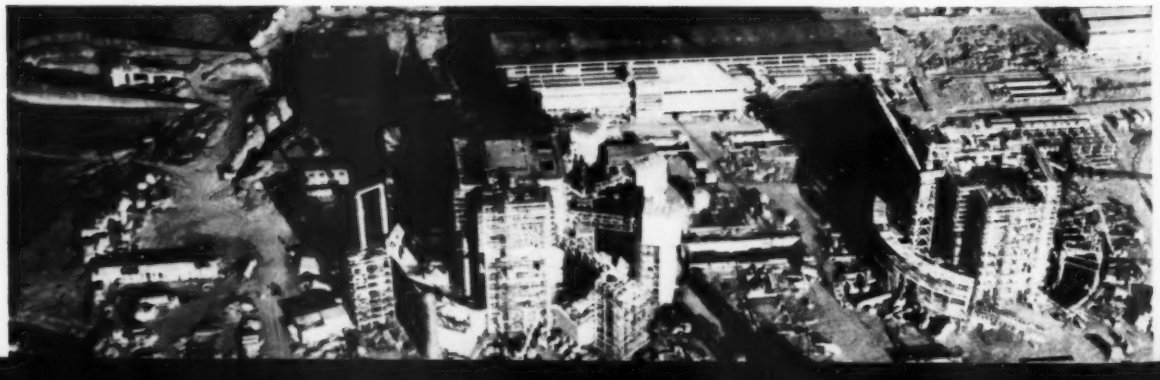

shows the Bailey bridge and cooling water intake which is rapidly taking shape. **7.** In front of No 1 reactor, No 2 reactor vessel and its steel thermal shielding are being built beneath the sheltering 'lid' in the foreground. The first heat exchanger is due in place by the beginning of March

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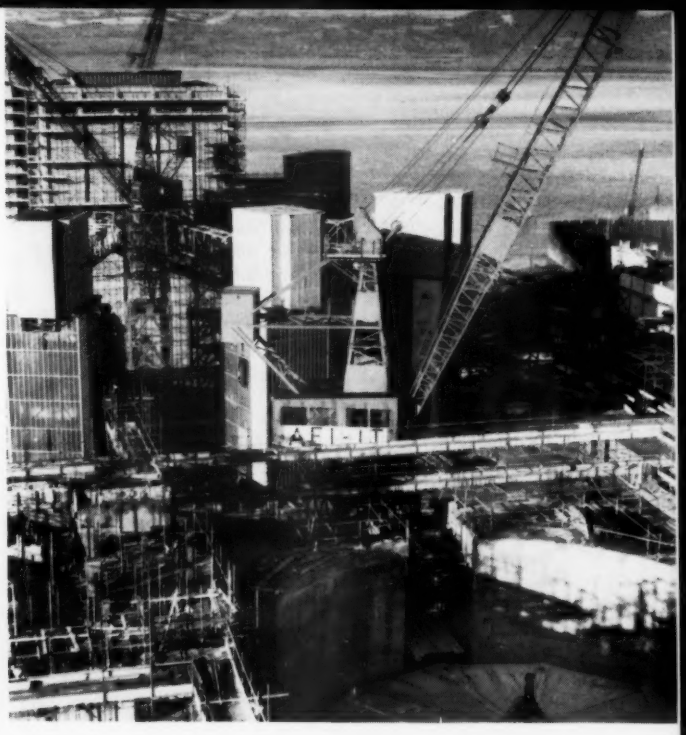


PROGRESS IN INDUSTRY

Radiation windows in production

pioneer work by Chance-Pilkington

COMPLETE CUSTOM-BUILT solid glass radiation shielding windows are now being produced at St Asaphs, in North Wales, by the Chance-Pilkington Optical Works. Installations have been made for the Atomic Energy Authority and several overseas atomic energy commissions as well as for a large number of industrial hot laboratories and hospitals. Construction of the factory, which was designed primarily for the production of high quality optical glass, began in September 1956 and the first glass was produced in June 1957. The flow line has been made so versatile that the output can take in a wide range of products from ophthalmic lens pressings and optical glass in extruded strip form to casting large glass blocks—this form of production has proved an ideal method for the manufacture of radiation shielding windows and is based on the strictest possible control of materials and operations at all stages.

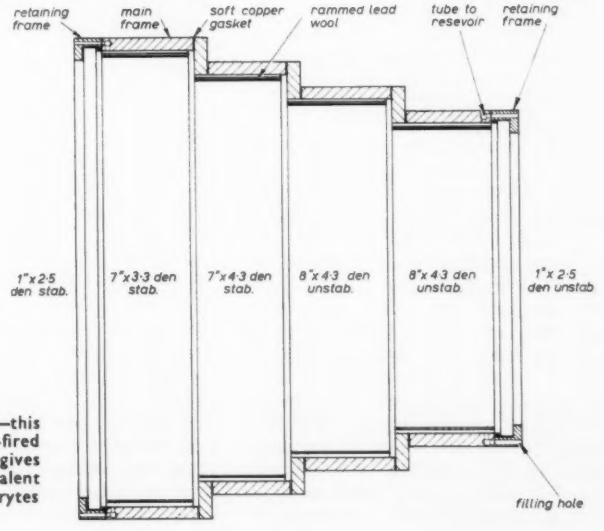
Balancing concrete/glass densities

Protection against radiation can be satisfactorily achieved by glass where the absorbing power is dependent upon its thickness and its density. As it is desirable not to have a window thicker than the main surrounding structure, the wall density becomes the governing factor. In normal concrete construction (2·5 density) normal lime-soda plate glass, of approximately 2·5 density, is employed. When barytes concrete (3·3 density) construction is involved an extra dense flint lead glass is used which has a density of 4·3. Where a multiplicity of glasses are mounted together, interference from inter-surface reflexion is eliminated by introducing a liquid of similar refractive index to that of the glass between the plates.

Normal glass when exposed to X-rays or gamma rays is subject to staining or discoloration. The discoloration can be controlled by the addition of a 'stabilizer' to the raw materials during manufacture. Whilst the stabilizer does impart a slight yellow tint to the glass it does substantially prevent staining when the glass is subsequently exposed to the higher intensity radiations.

Casting large glass blocks

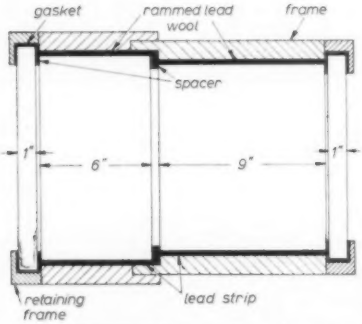
All raw materials are initially analysed by the Chemistry Laboratory and after being approved are weighed ready for batch mixing. The mixing time is carefully controlled as over-



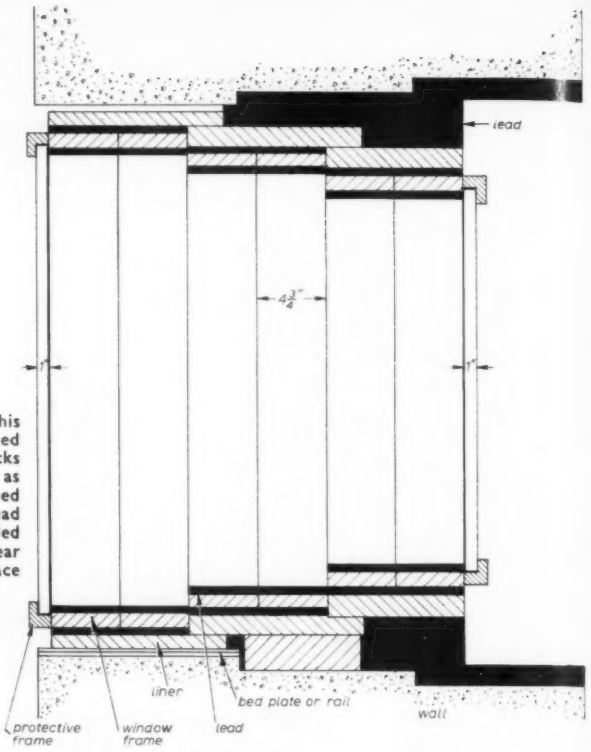
FOR REACTORS—this four block oil-fired radiation window gives protection equivalent to 36 in. of barytes concrete

mixing tends to separate out the constituents; when completed the material is transferred to special metal-lined wooden batch boxes. The tank method of production is employed so that all the operations necessary to obtain the glass melt are on a continuous scale, from melting the raw mix of predominantly carbonates and nitrates causing them to decompose to their oxides and resulting in gases forming bubbles within the glass; raising the furnace temperature to lower the viscosity of the glass to liberate the gases and after the glass is bubble-free; stirring to ensure homogeneity; finally cooling to ensure that the viscosity of the glass is suitable for the subsequent casting or forming operations. This continuous method of production enables very close control of quality to be kept and constant sample testing allows any fault apparent to be corrected during the course of manufacture.

When casting large shielding windows the output of the tank is fed into a mould located within an electrically-heated casting chamber or muffle so that throughout the loading the glass is held at the correct casting temperature. When the mould has been filled it is passed to a large annealing kiln or muffle where controlled rate of cooling ensures that the residual stresses in the glass when cold are well within the limits of safety. The time taken to complete this annealing process depends upon size and in the case of large blocks will be eight to ten weeks. The cast glass is checked by the laboratory for density and refractive value as well as being examined for any striae or other imperfections within the block. The annealed block is then sawn to size and thickness on a bandsaw, ground and polished to a good felt polish standard on large working tables. Blocks of 4·3 density can be made in this manner up to 5 ft 6 in. square with a thickness of 10 in. giving a finished thickness of up to 8 in. The standard of flatness obtained is not comparable to that of optical instruments but the surfaces of the glass are well polished giving high transparency and suitable for the surfaces of shielding windows.



FOR HOSPITALS—used for observation in radiation treatment this dry window comprises two blocks with thin glass cover plates



FOR HOT LABS—this is a specially designed unit of six blocks which is removable as a whole on a bed plate. Additional lead shielding is provided to screen the rear frame and access space

Window design

Standardization proving impracticable each shielding window requirement is considered independently to get the most efficient and economical window. A specialized design department has been set up and facilities exist in the works to cover all the fabrication and assembly requirements of the necessary steel retaining frames, lead blocks and sealing, gaskets and where applicable, oil-sealing systems, together with personnel for site installation.

These shielding windows are fabricated in a wide range of sizes from single blocks of glass to multi-section windows incorporating as many as six stabilized and unstabilized blocks with front and back cover plates which with the associated frame and packing can weigh anything up to 6 tons. Normally in a multi-plate window, only the first few plates on the 'hot' side need to be stabilized; the remainder on the 'cold' side can be of unstabilized clear white plate glass composition. In the design stage of the window it is advantageous to splay out the surrounding wall on the 'hot' side to give a wider field of vision. Tests have indicated that the minimum size of window on the 'hot' side necessary to give the maximum field of view is approximately 48 in. × 30 in. This could be tapered down on the 'cold' side to either 36 in. × 24 in. or if necessary 24 in. × 12 in. It is considered satisfactory if the windows are stepped downwards by not more than 6 in. in each direction per step, i.e. a 3 in. step on each edge.

The glass blocks are packed in a bolted and welded steel frame or tank with lead strip and wool packing so that the glass is held rigidly within the frame. If more than one block is used gaskets are inserted between the blocks to locate their relative positions and as each block is fitted the assembly is tested to ensure that it is free from optical interference faults. In the construction of 'dry' windows, thin gaskets holding silica-gel are used whilst copper gaskets are employed in assemblies that are oil-filled between the blocks. With the large windows the usual practice is to include cover plates on each end of lower density (2·5) which are gasketed into position to ensure that the whole assembly is effectively airtight and alpha contamination is limited only to the 'hot' face. These plates also afford protection in that if the window is damaged by impact it is only these relatively cheap pieces of glass which are affected.

Special requirements

In certain circumstances where it is desirable to be able to withdraw the shielding window from the surrounding wall assemblies are made complete with bed-plates and rails to facilitate withdrawal with lead surrounds in the wall for access space shielding.

Cross Section by GRACCHUS

APART from the effect in his own Nuclear Power Plant company, the death of Claude Gibb at the height of his career will be felt throughout the British nuclear industry. His belief and confidence in the gas-cooled reactor and his admiration for its main architect Sir Christopher Hinton were so unshakable that to many he must have seemed obstinate. Like many physically small men, Gibb thought very big and never did things by halves. Still comparatively rare amongst top business management, Claude Gibb was a first class engineer with a lot of intuition and he always rather reminded me of one of the great Victorian engineers such as Telford or Brunel. In business he was among the toughest, yet he was a warm, genial talker on informal occasions although once he had formed an opinion it was well-nigh impossible to shake him. It is sad to think that his last journey was the homeward one from negotiating against severe American competition a £M4·2 contract for a 500 MW turboalternator for the Tennessee Valley Authority.

Although Gibb was engaged in a tremendous commercial competition with the other atomic power groups he always put Britain first and we had no more skilled advocate than he. This story is typical. When his firm was awarded the supreme Grand Prix for the best nuclear exhibit at the Brussels exhibition, we sent him a congratulatory telegram. Within hours the reply came 'we too, were glad that Britain won the premier award.—Gibb'!

At a recent London meeting, Gibb had just finished answering questions from the platform. My neighbour—an AEA official—whispered in my ear. 'He's always good value!' He was too.

BIG changes in the top stratum of the Atomic Energy Authority are due soon. Sir John Cockcroft is now returning to Cambridge as Master of the new Churchill College: Bill Strath, the popular member for External Relations and Commercial Policy, is off shortly to the Ministry of Supply as Permanent Secretary: Sir Edwin Plowden, Chairman since the Authority's inception in 1954, will be leaving later this year. Strath's successor, Sir Alan Hitchman, has already been announced but there is considerable speculation as to who will replace Sir John and Sir Edwin. Pretty obviously, the Member for Research must come from inside but there is certainly no obvious choice for the job. Sir William Penney could of course do it but he is already Member for Weapons Research and such a move would still leave a hard vacancy to fill. For Chairman, the Prime Minister will probably have to look elsewhere. Now that Euratom and the Common Market are in operation British nuclear energy faces some tough commercial problems and I hope Mr Macmillan will turn to industry rather than the Civil Service to fill this key post.

TWO completely new types of reactor—the Krupp potato or hard-boiled egg machine and a nuclear ship, both announced in a week—is not bad by any standard: from Germany—a country on its back 12 years ago, it is astounding.

With the news of Interatom's ship reactor prototype the organic moderated reactor concept must clearly be taken more seriously than in the past. Atomics International and in particular Chauncey Starr, have worked very hard to put over the OMR and the fact that the Germans have now accepted it must be a source of great satisfaction. In the latest brochure from the firm they are offering firm price quotations for complete 150 MW land stations with guaranteed plant performance.

Critics of the OMR have damned it for the polyphenyl moderator's tendency to build up polymerization products under irradiation. In the fully productionized OMR this is to be got over by the simple expedient of distilling continuously a small fraction of the coolant-moderator, residuals apparently being suitable for burning in a conventional boiler for water distillation. We thus have a miniature oil-refinery alongside the power station.

THE Institute of Physics' recent symposium on fuel cycles was I felt conducted in a rather unreal atmosphere. Here were top level scientists talking glibly about whipping fuel out of one part of the reactor and inserting it somewhere else in one non-stop belt when in fact it will be at the very least two years before this becomes a practical problem. Of course it is necessary that these things are all thought out in advance but satisfying the physicists' demands for optimum efficiency is going to tax the charge machine designers and plant operators to the utmost.

A factor contributing to the atmosphere was the fact that the papers were not available beforehand and the authors only had a limited amount of time to present them. In a highly technical conference like this preprints are absolutely essential if discussion is not to be completely vapid. As it was, much time was wasted by speakers criticizing the omission of some point or other only to have it explained by the author that it was fully covered in his paper but he hadn't time to mention it in his oral presentation.

During the proceedings I was struck by how much physicists now have to know about economics. Once upon a time they knew little and cared less about risk capital, plant amortization and interest charges. Now these quantities have become mixed up with excess reactivity, thermal ratings and burnup and it is almost possible to place a monetary value on a single neutron. Which shows, I suppose, that physics has become big business.

THOSE of my readers who are top people will probably have read this story in their favourite newspaper but for the benefit of those who are not I repeat it. I hasten to add that I did not find it myself: my attention was drawn to it. It seems that Blackwell's, the Oxford booksellers, recently sold to an American an autographed copy of Rutherford's *Radioactive Substances and their Radiations* from the library of the late Professor Soddy. The customer wrote 'knowing the haphazard manner in which radiation was handled by such pioneers as Soddy and Rutherford it occurred to me that the book might be radioactive.' So he tested it and recorded 1000 counts per minute of an alpha-emitting substance on the inside cover. Pulse analysis did not give a positive identification but he considered it 'probable that the substance is indeed radium. The amount of contamination is, of course, not dangerous.'

On Record

In a democratic country, no atomic energy organization can function effectively unless it carries public opinion with it.—E. H. Underwood, UKAEA.

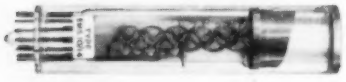
New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

HIGH-GAIN P/M TUBE

miniature model

20th Century Electronics Ltd have developed a miniature high sensitivity photomultiplier only ¼ in. in diameter and less than 4 in. in length. A box-type structure of 10 dynodes it has been designed to provide extremely high collection efficiency and eliminate 'stage skipping.' By the use of a new dynode activation technique very high stage gains are



The new 20th Century tube uses a new dynode activation technique which gives high gain with low noise

achieved and the tube possesses a signal to noise ratio many times less than equivalent American tubes of the same size. The multiplier is fitted with a special 12-pin moulded glass base for which moulded sockets are available.

Because of its small size and high sensitivity, this photomultiplier may find wide application in geological scintillation counting apparatus and in photoelectric auto collimators and spectro photometers. When coupled as a scintillation counter to a ½ in. dia sodium iodide crystal, a resolution of the order of 10% is easily obtained with caesium-137 claims 20th Century. With an interdynode voltage of 100 volts, the tubes have a minimum overall sensitivity of 150 amps per lumen.

Tick **No 208** on reply card

PLASTIC SCINTILLATORS

beads for liquid counting

For use in aqueous scintillation counting applications, Pilot Chemicals Inc announces the development of plastic scintillator beads called B-BEADS. Fabricated from Pilot Scintillator B filaments, B-BEADS are in the form of tiny cylinders measuring approximately ¼mm diameter × ¼ mm long.

In this form, the scintillating surface is maximized while at the same time some of the 'light-pipe' properties of the filaments are retained. B-BEADS can be poured from container to container, remain unaffected by water and lower alcohols, and can be used in conventional refrigerated counting chambers.

Preliminary experiments with this material at the National Institutes of Health indicate excellent results using scintillator beads to measure radiation in water solutions containing carbon-14. It is expected that B-BEADS will find wide use in the application of liquid scintillation counting methods to many biochemical tracer studies.

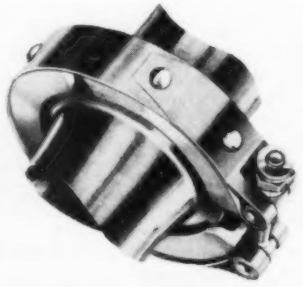
Tick **No 209** on reply card

PIPE COUPLING

high temperature, pressure

Design of pipe joints and couplings for use at elevated temperatures has to a great extent been dictated by the availability of suitable resilient gasket materials. Conventional asbestos impregnated materials and metallic reinforced gaskets are limited to a temperature range in the proximity of 400°C, and not all offer corrosion resistance to a variety of chemicals.

King Aircraft Corporation have now developed and tested a pipe coupling to meet these requirements at pressures in 6000 psi range. Termed *Conoseal*, the unit is based on the Vee-Band clamp principle and together consists of a male



The Conoseal coupling is all-metallic. It is suitable for pressures up to 6000 psi and temperatures to 980°C

and female flange and all-metallic gasket. The flanges are suitable for either lap or butt welding to the pipe line or duct. The standard range offered covers pipe bores from ¾ in. to 10 in. diameter, and can be supplied in aluminium alloy, mild steel, stainless steel or Inconel materials, dependent on the temperature and fluid characteristics involved. Non-standard couplings have been manufactured up to 36 in. diameter. The operating temperature ranges from −184°C to +980°C.

The V-clamp type coupling is claimed to offer great advantage where rapid connexion and disconnexion is required. Low weight and small envelope characteristics are considerable when compared with bolted flange joints. The *Conoseal*, by virtue of its all-metallic construction, has a wide application for pneumatic and hydraulic control lines, is resistant to liquid CO_2, liquid nitrogen and liquid sodium. It is being applied successfully to coolant and purging systems for nuclear power plant installations.

Tick **No 210** on reply card

LEAK TESTING

French helium spectrometer

Helium is used as the leak detection medium in the Helitest separately-magnetized spectrometer. The robustly constructed detector unit is capable of tracing one part helium in five million parts air and can be used in all types of industrial application.

To detect leaks in a closed system, the vessel is evacuated down to 1/10 mm. Hg, a fine spray of helium is passed over the outside of the vessel and when gas comes near any apertures, it is drawn into the system and then carried through to the detector, which immediately announces the presence of helium. Using the vacuum method, it is possible to test leaks as low as 10^{-10} atmos. per cc per sec., i.e., less than 10^{-7} lusec. Another method is to pressurize the system under test with a gas containing helium; the suspected surfaces are probed with an aspirating nozzle connected to the detector.

The *Helitest* is manufactured in two models; one automatic, the other manually operated. Accessories include a vapour and condensate trap cooled by liquid nitrogen and is mounted at the inlet to the unit, a degasification chamber (supplied with the automatic set) and a standard test leak. The equipment is manufactured in France by Le Laboratoire des Basses Pressions and is handled in the UK by Appleby and Ireland Ltd.

Tick **No 211** on reply card

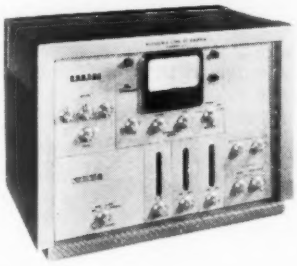
SCALER/RATEMETER

universal US instrument

Developed with an eye towards both the individual research worker without ready access to electronic servicing, and the large laboratory wanting complete equipment that will never become obsolete, The Nucleonic Corporation of America's *Universal* scaler features interchangeable slide-out units that plug-in quickly, giving any combination of features from simple to complex.

Three amplifiers, 4 binary scalers, 6 decade scalers—either strip or glow tube, 5 registers, 6 timers, 2 high-voltage supplies, 1 analytical ratemeter, are currently available. Also provided for in the *Universal* scaler are outlets for automatic sample changer, and digital or timer

print-out equipment. Plug-in amplifier input sensitivities range from a fraction of a millivolt to 9 volts for binary and/



Designed to appeal to workers having little specialized knowledge of electronics, the Universal Scaler makes extensive use of plug-in units

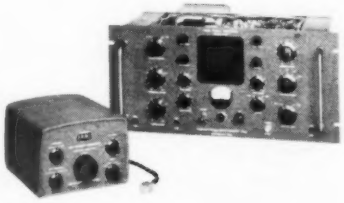
or decade scaling units, allowing any scaler function to be performed within the limits of binary 64-4096, and decade 100-1,000,000, simply by adding the units desired.

Tick **No 212** on reply card

NMR SPECTROMETER

addition to US range

A new nuclear magnetic resonance field control unit, the FC-501, has been produced by Harvey-Wells Electronics, US. Designed to provide a means of precise regulation of electromagnets by producing an error signal, derived from the field under control, which is suitable for



The equipment consists of a gauss meter and probe (left) and a field control unit (right)

closed-loop regulation of the magnet power supply, its range is 310 to 20,000 gauss with standard probes. For control of fields out of this range special probes are available. The FC-501 consists of three interconnected parts: (1) probe, (2) oscillator, (3) field control unit, made up of a power supply, lock-in amplifier and modulator. Oscillator stability is greater than ten parts in a million, and the modulation sweep range is zero to 20 gauss. The unit operates at 115 volts, 60 cycles at 2·5 amps. Both the oscillator and field control unit weigh 45 lb. It can also be used as a high gain null detector for precise control of temperature, pressure, and impedance by the addition of an external bridge.

Tick **No 213** on reply card

WATER LEVEL OBSERVATION

new television system

A new system of remote observation of boiler water level has recently been introduced by Hopkinsons Ltd. It consists of a scanning unit, a cathode follower and a display unit. The scanner and C.F. units are located together but the display unit may be situated at some distance. The equipment is arranged to be used with a prismatic water level indicator, of either plate or ' bulls-eye ' type, in conjunction with an illuminator fitted to the water gauge; no external illumination is necessary.

The scanning unit houses a lens, scanning disk and photomultiplier. The scanning disk has a narrow slot with variable radius and is rotated at exactly the mains supply frequency by means of a synchronous motor locked to the mains period. Light from the illuminator, associated with the water gauge, passes through the prismatic indicator in such a way that the steam space appears as intense clear light and the water column as dull diffused light.

The scanning unit is placed so that the light from the gauge passes through the lens to a focal plane coincident with the scanning disk. In front of the latter is a fixed vertical slot, and as the disk rotates, the disk slot and the fixed slot together form a gate admitting light at all points along the fixed slot progressively with respect to time. Thus the gauge glass is ' scanned ' and the gated light is allowed to fall on the sensitive surface of a photomultiplier. The voltage produced is transmitted along a cable to the display unit, and is transformed back into light by the cathode ray tube. Deflexion of the beam of light on the cathode ray tube is exactly synchronized with the scanning motion.

The photomultiplier is insensitive to the water column in the gauge, since the main light from the illuminator, passing through water, is refracted outside the scope of the narrow vertical slot in the plate behind the lens, and the dull diffused light coming directly through the water column is insufficient to activate the light-sensitive cell of the multiplier.

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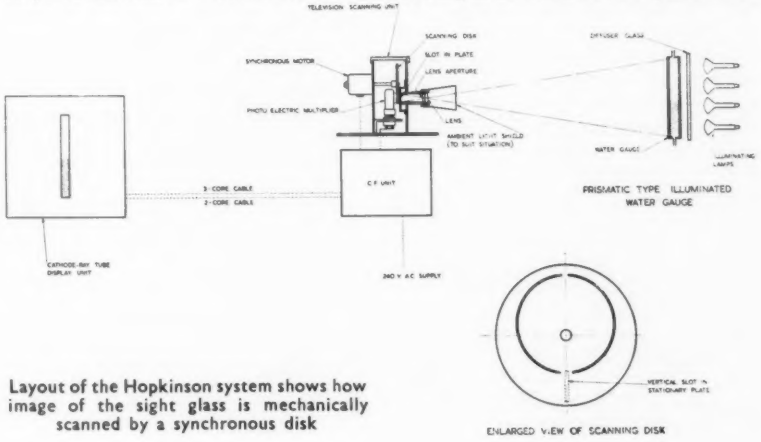
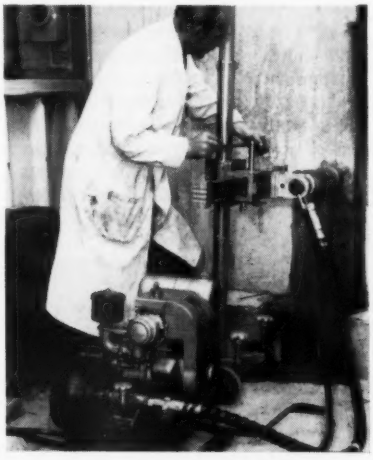


Layout of the Hopkinson system shows how image of the sight glass is mechanically scanned by a synchronous disk

HOLES IN CONCRETE

diamond drilling

Equipment for drilling holes in rock, concrete, brick etc of particular interest in nuclear energy applications was demonstrated in London recently. Known as the Diatube system, it is based on



The Diatube/Flextol heavy duty unit in action. This one is petrol-driven

the use of diamond-tipped core drills similar to those used for many years for taking mining core samples.

Holes from $\frac{3}{8}$ to $1\frac{1}{2}$ in. dia can be driven using a portable power drill with standard $\frac{1}{2}$ in. chuck. Up to 6 in. dia the standard Diatube drill stand is used with Flextol electric, petrol or air power units. The drill stand has a rack and pinion feed and can be angled to any position. Using special heavy duty equipment, holes of up to 12 in. dia can be driven to distances of many feet. Water cooling is used and an anti-splash attach-

ment is available for cases where it is needed.

We understand from Holemasters Ltd that in addition to sales the equipment may be hired and that work is also done under contract. A recent job was at Berkeley power station and a forthcoming one is the drilling of a heavy aggregate biological shield at an AEA establishment.

During last year's re-erection of some fallen stones at the Stonehenge ancient monument Holemasters were asked to drill through some of them that appeared to be badly cracked. Complete cores about a yard long were obtained broken only at the cracks. The holes were later filled with metal rods.

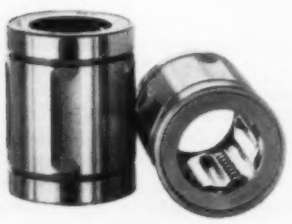
At the demonstration we were able to see specimens of holes and cores in reinforced concrete, brick, terrazzo, solid granite, agate and blast furnace slag.

Tick **No 215** on reply card

LINEAR MOTION

recirculation ball bushing

Low friction linear motion has for long been one of the mechanical engineers most difficult problems and this is especially true in reactor technology where control rods for example have to be



Unit on the right shows the arrangement of ball tracks which are completely contained in the bushing

positioned with extreme accuracy. What is claimed as a major advance in this field was announced recently by Ransome & Marles Bearing Co Ltd. This is a recirculation ball bushing of a type already in wide use in the United States and for which the company now has sole manufacturing and selling rights for the UK and Commonwealth except Canada.

The bushing contains a number of linear ball tracks consisting of a race-track section pressing, one leg of which is partly cut away to expose the balls. This is the load-bearing part of the bushing. The other leg of the track is covered over and is not in contact with the journal. Through here the balls recirculate to their starting point.

Eleven shaft sizes from $\frac{1}{4}$ in. to 4 in. are available: corresponding outside diameters of the bushes are $\frac{1}{2}$ in. to 6 in.

Tick **No 216** on reply card

IN BRIEF

Transportable diesel The *Vega*, a new air-cooled range of diesel engines in the 200–400 b.h.p. range has been introduced by Davey, Paxman & Co Ltd, which are especially suitable for use in transportable rigs and for use on construction sites. At the same time, the *Ventura* range of V type diesel engines of between 1100 and 1735 b.h.p. now supplements the earlier Davey, Paxman V-engines—these are available in both pressure-charged and pressure-charged/intercooled forms.

Tick **No 217** on reply card

Pressure and vacuum testing A portable item of test equipment for checking both pressure and vacuum systems at positive and negative pressures within the range of 1 psia to 115 psia has been developed by Bryans Aeroquipment Ltd. The gauges in the test may be checked without removal from the case, against a standard such as a manometer, gauge or other means of reference. The Tester is connected to a standard reference and the pump operated to the required pressure. A comparison is then made between the reference and the test set gauge.

Tick **No 218** on reply card

Laboratory pumps The new *Genevac* single-stage high-vacuum rotary piston pump is in 2, 4, 8 and 12 cu/ft/min. capacity with an ultimate vacuum of less than 0·005 mm Hg. The double-stage model is in 2, 4 and 6 cu/ft/min. capacity with an ultimate vacuum of less than 0·0002 m/m Hg. The design permits of higher pumping speeds at 100 microns and the pressure rise is less than 0·5 mm Hg with maximum ballast. These pumps are now in production by Genevac Ltd, a new subsidiary of General Engineering Co (Radcliffe) Ltd.

Tick **No 219** on reply card

Diffusion pump The F1203 fractionating oil diffusion pump has been added to the Edwards High Vacuum *Speedivac* range, to fill the gap between the 9 in. and 16 in. models. These fractionating diffusion pumps are now available in a complete series of sizes from 2 in. to 24 in. bore, with speeds between 80 and 12,000 litres per second.

Tick **No 220** on reply card

Counter The Type 100 Electric Counter produced by Counting Instruments Ltd can now be supplied with electrically-operated resetting facilities. This takes the form of a solenoid mounted at the rear of the case, which momentarily energized operates the resetting mechanism to return the counter reading to zero.

Tick **No 221** on reply card

Transistorized recorder Fielden Electronics, Ltd, have brought out a new transistorized four-point temperature recorder with a 10 in. dia chart. Resistance bulbs are used as the temperature sensitive elements.

Tick **No 222** on reply card

Boiling in nuclear reactors—Pt 2

continued from page 101

Acknowledgements

In a review article of this nature the opinions presented are the result of a synthesis of ideas derived from a wide number of individual papers and from personal discussions. In the list of references it is impossible to list each source individually but the many published papers of L. Bernath, M. Jakob, S. S. Kutateladze, R. Larson, W. M. Rohsenow and colleagues at the Massachusetts Institute of Technology, and J. W. Westwater, to name but a few of the workers in this field, have been found particularly valuable.

It is a pleasure to acknowledge also the valuable help received in discussions with Dr J. Woodrow, Dr N. Zuber, R. W. Haywood and D. J. Higson.

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INDUSTRIAL NEWSDESK

New Rolls-Royce move

A new nuclear engineering company has been formed by Rolls-Royce Ltd, Vickers Ltd and Foster Wheeler Ltd, known as Rolls-Royce Associates Ltd. The initial capital is made up of 250,000 £1 shares, of which Rolls-Royce hold 52% with Vickers and Foster Wheeler 24% each. This new company is rather similar to Vickers Nuclear Engineering Ltd (VNE) which has an issued capital of a thousand £1 shares, 993 are held by Vickers, one share by each of VNE directors Maj-Gen C. A. L. Dunphie (chairman and managing director of Vickers-Armstrong), Lord Hives (former chairman of Rolls-Royce), Mr G. H. Hopewell (managing director of Foster Wheeler), Rear Admiral Sir Leopold E. Rebbeck and Lt-Gen Lord Weeks (director of Vickers) and one share each by Mr John Mclean and Mr E. P. Tomlinson. Despite this similarity overlapping of activities will be minimized in that VNE will continue to cover all types of nuclear projects in their initial stages and specific projects will be handed over to the new company for completion. At present this arrangement means that the design team responsible for the Admiralty nuclear powered submarine project will work under the aegis of Roll-Royce Associates.

Flanges from Lintott

Forged alloy steel flanges are now being produced in quantity in the UK by H. & E. Lintott Ltd. Under the name *Linflange* a wide range of welding-neck, slip-on, lap-joint, threaded, blind, socket-type, reducing, orifice and special flanges are made for high temperature and pressure conditions — alloys particularly applicable to the nuclear, petroleum and chemical process engineering are being worked to meet all requirements between ½ in. and 12 in. nominal bore sizes and which should greatly ease the design and fabrication of pipe-layouts.

Marconi's spring plans

Following successful prototype trials in a new department set up last year at their St Albans works, Marconi Instruments are soon to start production of a considerable range of nucleonic instruments. This was stated by general manager R. E. Burnett inaugurating a week's special exhibition of his firm's communication instruments at London's Waldorf Hotel on Jan 19. Mr Burnett said the nucleonic field was new to Marconi but they were now responsible for the system's engineering of nuclear instrumentation at Hinkley Point power station. This called for flux measurement, burst slug detection, stack filter checking and general health monitoring. Hinkley would, however, be merely a start and it was hoped to compete in exports as well as help in meeting home demands.

Parsons buy US fuel

A contract for the precision sintering of uranium dioxide, a nuclear fuel material, has been awarded to Nuclear Materials and Equipment Corporation (NUMEC) of Apollo, Pa, by C. A. Parsons & Co Ltd, Newcastle-on-Tyne. This material will be prepared and fabricated by NUMEC into high density specialized oxide shapes to be used in reactor fuel elements of advanced design being developed by Parsons in conjunction with its subsidiary, The Nuclear Power Plant Co Ltd. This order is in addition to those placed by the Italian company, Agip Nucleare, and the French Government (*Worldview*, last month). NUMEC expect to announce other foreign contracts in the near future.

Industrial brazing service

A new specialized brazing service has been introduced by Newton Victor Ltd, the X-ray department of Metropolitan-Vickers Electrical Co Ltd. The plant provides for the high quality brazing of components in controlled atmospheres and under vacuum. Radiation and muffle furnaces are included with which temperatures up to 1800°C can be achieved and parts up to 3½ in. sq and 10 in. long can be handled. Circular components up to 3½ in. dia and 3 ft 6 in. long are handled in 'eddy current' furnaces which give fairly local heating and temperatures in excess of 1100°C. The joints catered for include stainless steel to stainless steel, stainless steel to steel, copper to steel, steel to steel, copper to copper, steel to Nilo K, and Monel to other metals. A method of brazing beryllium has also been developed.

Transistors dissected

Since 1948 when the transistor was invented, no less than 800 different types have been produced. To review the whole field of transistors and semi-conductors, a Convention and Exhibition is being promoted by the Institution of Electrical Engineers at Earls Court from May 21 to May 27. During 23 sessions, more than 30 lectures will be given which will include basic theory, transistor materials, characteristics and their measurements, transistors as a circuit element, technology, design manufacture, applications and world trends. Although early transistors used a germanium crystal, silicon is becoming increasingly the preferred material as it has greater stability at elevated temperatures and has a higher reverse voltage rating and operates with much smaller reverse currents. To date much of the silicon of extreme purity for transistors has come from America or France but ICI have now brought into operation a large-scale development plant for the manufacture of semi-conductor grade silicon. The plant will be operated by ICI's General Chemicals Division on Merseyside and by the middle of this year output will be running at the rate of some 4000 lb per annum.

SOVIET DELEGATION AT PLESSEY'S

Russian scientists recently visited Plessey Nucleonics at Northampton when Mr Khrustalef (first left), Mr Andreev (second left) and Mr Khanzhenkov (far right) inspected a precipitator used with Plessey's burst slug detection system

AEA reports on microfilm

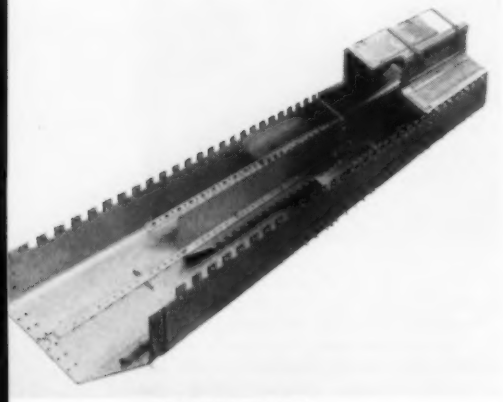
To make atomic information more easily available, the UKAEA has decided to extend its use of microphotography and all non-secret reports which have been prepared since 1947 will be obtainable. A large number of unclassified and declassified reports, which so far have been

obtainable only on loan from AEA libraries, will be available in microform. Micro Methods Ltd, of East Ardsley, Wakefield, Yorks, will produce the microcopies on card of these reports issued between 1947 and December 1956 and, on a continuing basis of subsequent reports which are not available on sale from HM Stationery Office. A complete list of these reports may be obtained from Micro Methods. Complete sets of these reports are being presented to a number of other countries and to certain international agencies. In addition to this the Authority is increasing its facilities for supplying reports in conventional form as they are prepared.

More nuclear this year

Honorary President of this year's Engineering, Marine, Welding and Nuclear Energy Exhibition is Sir Edward Thompson, JP, chairman and managing director of John Thompson Ltd and president of the British Engineers' Association.

Open from April 16–30 at Olympia, London, the exhibition, traditionally an autumn fixture but now moved to the spring, will include over 500 exhibitors showing more than 1000 categories of engineering products. Although it has changed its name several times over the years, the exhibition has a history going back to 1906. The organizers expect a big increase in nuclear exhibits this year, all of which will be reviewed in a NUCLEAR POWER special issue.



FAIREY NUCLEAR

Typical of Fairey Aviation's expanding activities in nuclear engineering is this partly assembled core skirt for the Dounreay fast reactor. The castellations assist assembly and obviate overlap

Sizewell coastal check

The preliminary marine survey has been completed for the proposed sixth nuclear power station at Sizewell, Suffolk. With a planned capacity of 650,000 kW this is the largest projected nuclear power station in the United Kingdom. Surveys covering harbour facilities, feed water inlet and exhaust were made by Kelvin & Hughes (Marine) Ltd, for Messrs Mouchel & Partners on behalf of the Central Electricity Generating Board. The Kelvin-Hughes Contract Survey Department carried out similar marine surveys for the Bradwell, Berkeley, Hinkley Point and Hunterston nuclear plants.

Another alloying metal?

Yttrium metal has been produced by the US Bureau of Mines in a form which may provide the solution to a number of reactor engineering problems. This metal which has been long considered too brittle for 'structural' uses has now been obtained in high purity state having good ductility. The method employed was a process similar to that used by the Bureau which provided titanium and zirconium on a commercial scale. The potential value of yttrium lies in its relatively low microscopic cross-section and its relatively high melting point, over 1500°C which opens up the possibilities of making a range of steel-based alloys to meet the increasingly rigorous specifications for high temperature reactor components.

Ekco deliver for DR3

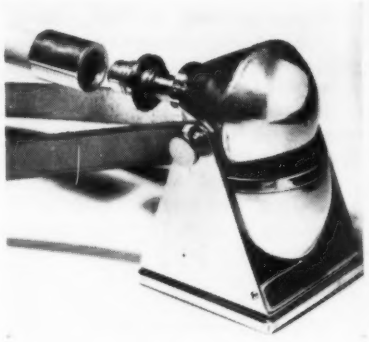
Better guard and interlock circuits have been incorporated in the nucleonic instrumentation for the Danish DR3 reactor. This equipment has been completed and pre-assembled by Ekco Electronics Ltd ahead of schedule and after inspection by the Danish Ambassador, will be installed at Riso. The experience gained at Harwell in the operation of the DIDO and PLUTO reactors has resulted in modifications being incorporated in the guard and interlock circuits as well as the layout of the control rods' instrumentation. Ekco's engineers, assisted by their Danish associates, will install and commission the equipment for the contractors.

Bigger and better seals

The increased demand for high temperature sealings has led to a big increase in the output of silicone rubbers which retain their elasticity at higher and lower temperatures than any other rubbers; for short periods, they resist temperatures of between 250 and 300°C, while at minus 80°C flexibility and electrical strength are not affected. In the nuclear field silicone rubbers have been used for O-rings, gaskets, wiring and electric motor insulation and to meet the increased applications generally, ICI have increased their output fivefold over the past twelve months. Towards the end of last year, another manufacturer of silicone rubbers, Midland Silicones Ltd, as a result of greater output reduced their prices by some 10% and have now announced a further reduction of nearly 20% which will doubtless expedite the more general use of these synthetic rubbers in industry.

Lighter isotope containers

'Safe at surface' isotope containers for gamma radiography are being made by Messrs R. F. Fraser-Smith for use with non-destructive testing techniques. Three sizes are available—small weighing only 8½ lb for thulium 170, standard weighing 30 lb for iridium 192 or caesium 137 and the large size weighing some 70 lb for cobalt 60. The standard container has been designed to give a maximum radiation level of 7·5 mr/h at the surface when loaded with 2½ curies of iridium 192. Alternatively, when loaded with caesium 137, the radiation level would be 7·5 mr/h at 10 in.



In readiness for higher activity thulium 170 is this Fraser-Smith lightweight isotope container

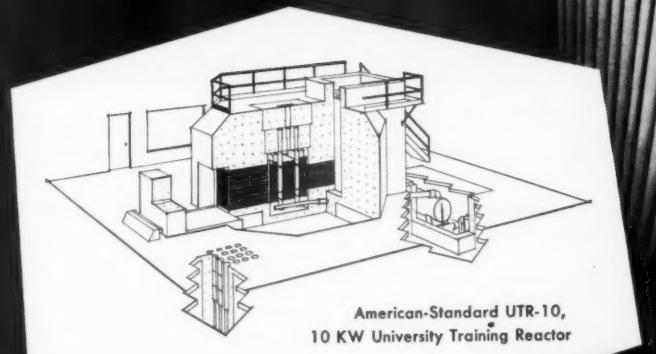
The small unit has been made in anticipation of the higher activities of thulium 170 which will shortly be available. With care, it could also be used by experienced operators for iridium 192, since the radiation would not exceed 7·5 mr/h at one metre, when loaded with 2½ curies.

The simple light-weight handling rod is suitable for all these containers and whilst the standard length is three feet, it can be supplied in any length required.

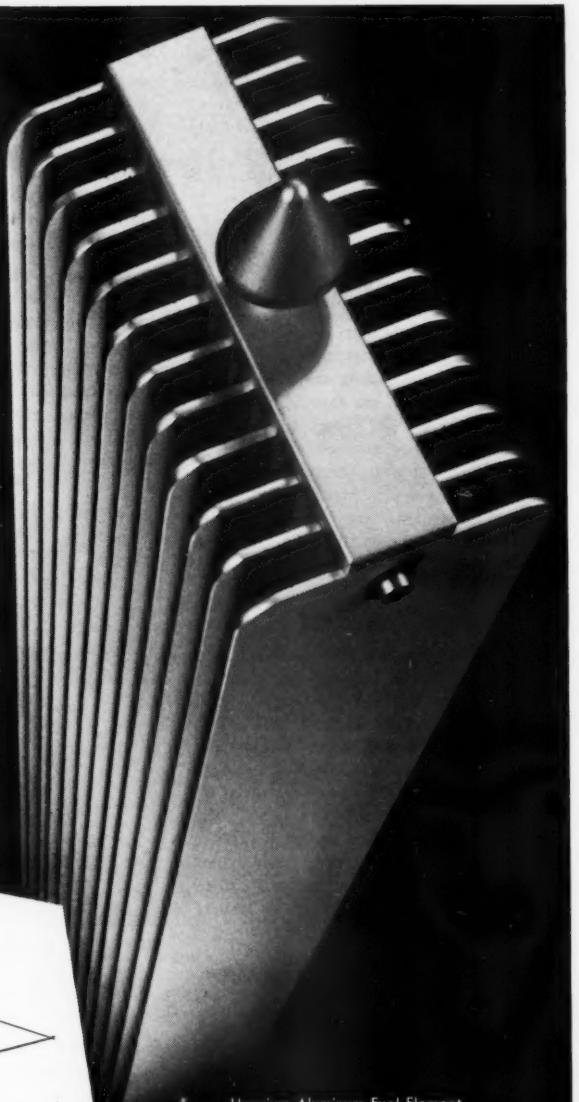
Doctors and isotopes

Radioactive Isotopes in Medicine is the subject of a course being organized by the British Council at Sheffield and Leeds next September. The lectures will range from the biological effects of radiation, detection equipment, counting techniques, to the use of isotopes in clinical investigation and treatment. The practical studies will include experiments on the use of various types of counting equipment for assay work and on in vivo detection methods. Particular attention will be given to radioiodine in thyroid disorders, radioisotopes in hæ-

Quality, Low-Cost FUEL for Training and Research Reactors



American-Standard UTR-10,
10 KW University Training Reactor



Uranium-Aluminum Fuel Element
Fabricated at M&C Nuclear

Experience at M&C Nuclear, Inc. in the fabrication of uranium-aluminum alloys clad with aluminum allows the low-cost manufacture of these fuel elements to meet the requirements for university training reactors.

The fuel plates shown were produced by M&C Nuclear, Inc. for American Standard, Atomic Energy Division, to be used in their university training reactors.

M&C Nuclear will be pleased to assist you in your experimental programs by supplying information on quality fuel based on your specifications and designs. Write our Manager of Marketing and Contract Administration.

The fuel plates, above, were manufactured to the following dimensions and specifications:

Weight	23 grams U^{235}
Element Length	25.938 ± .015″
Element Width	3.000 ± .015″
Element Thickness	.110 ± .006″
Fuel Thickness	.090″ nominal
Cladding Thickness	.010 ± .002″

Variations of dimensions are possible to meet special requirements.

M&C NUCLEAR, INC.

P. O. BOX 898, ATTLEBORO, MASSACHUSETTS, U.S.A.

FUEL ELEMENTS. CORE COMPONENTS. COMPLETE CORES

Tick **No 91** on reply card for further details

matological studies and determination of body radioactivity. The course is held in conjunction with the Universities of Sheffield and Leeds, the Sheffield National Centre for Radiotherapy, the Sheffield Royal Infirmary and the Leeds General Infirmary.

Combined specification

The British Standards Institution has issued a new publication covering 'Steel boiler and superheater tubes BS 3059 : 1958' which in fact contains 12 separate specifications for carbon steel and molybdenum steel tubes of varying form and tensile strength. To meet the needs of industry both hot finished seamless and cold drawn seamless carbon steel and 2¼% chromium/1% molybdenum steel tube requirements are included. This specification replaces BS 494, BS 512, BS 1653, BS 1654 and BS 1678.

Van de Graaff machines

We are informed by High Voltage Servicing Co Ltd that the name 'Van de Graaff' as applied to particle accelerators is the registered trade mark of High Voltage Engineering Corporation and that the only machines entitled to bear this name are those manufactured by HVEC. As is of course well known, the machine was pioneered by Dr Robert J. Van de Graaff, a director and chief physicist of HVEC. Inclusion of other companies under this head in our Buyers Guide (Jan) is not correct.

In brief

● **Alignment Gear** The complete range of Taylor, Taylor & Hobson's measuring instruments, machines and accessories will be exhibited at the Cheetham Public Hall, Manchester, from March 16 to March 21. New equipment will be included and surface finish and roundness measuring services will be available.

● **Test Certificates** A new electrical instrument test service has been established at the British Scientific Instrument Research Association's Chislehurst laboratories. It will be operated under the supervision of the National Physical Laboratory utilizing NPL certified equipment and will test and issue certificates for instruments up to precision grade accuracy.

● **De-centralization** To meet the changing pattern in its activities the Sperry Gyroscope Co Ltd has established three separate operating divisions. The Industrial Division will be responsible for the hydraulic and electro-mechanical applications and equipment together with non-destructive testing equipment for nuclear energy projects and process control work.

● **Sinter Production** Increases in the demand for sintered metal products have necessitated expansion by the Morgan Crucible Co Ltd. The opportunity has been taken to meet this requirement to establish a new factory at Wandsworth and at the same time incorporate a new laboratory and sales office for the production and development of Sinterlink.

● **Submarine Check** Controls for Radiation, Inc have been awarded a contract by Knolls Atomic Power Laboratory of GEC for radiochemical analyses during the start-up of the nuclear submarine *Triton* and will include the measurement and identification of radioactivity induced in the heat-transfer medium of the reactor propulsion systems.

● **Electronic Exhibition** The third annual exhibition by A. M. Lock & Co Ltd will be held at the Bennett Hall, Snow Hill, Birmingham, between March 17 and March 20, when more than 400 instruments and controls will be displayed.

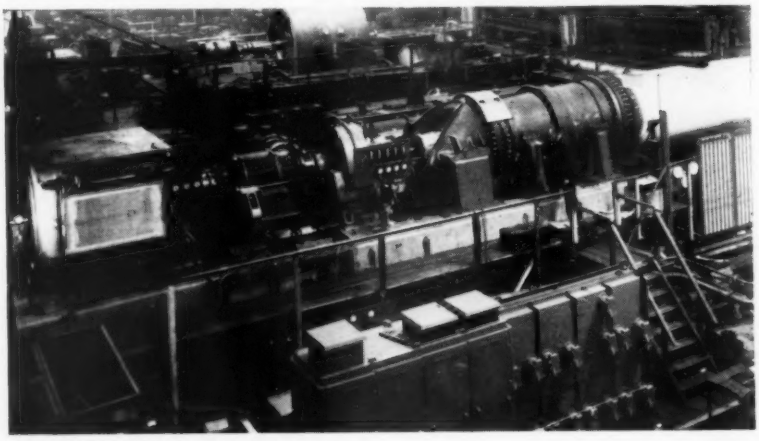
● **International Computers** The British Tabulating Machine Co Ltd has merged with the Power-Samas Accounting Machines Ltd, to form International Computers and Tabulators Ltd (ICT). With capital assets valued at nearly £M24, ICT plans a steady development of the Commonwealth and European markets for punched card equipment and electronic computers with special reference to data processing machines.

● **GCRE second phase** The reactor vessel and equipment including instrumentation for the Gas-cooled Reactor Experiment Facility will be supplied by Anderson-Burke Corporation to the AEC.

● **Continuous Running** At the electrical engineers exhibition one of several 250 hp 3000 rpm squirrel-cage motors supplied to the UKAEA is shown by Laurence, Scott & Electromotors Ltd. This type is designed to run for a minimum of two years without shut down.

● **Power Convention** 'Electricity and its contribution to the standard of living' will be the theme of the eleventh British electrical power convention and exhibition being held at Torquay from June 1 to June 5. A paper 'Progress on the first nuclear power stations—Bradwell, Berkeley, Hinkley Point, Hunterston' will be given on Tuesday morning June 2.

● **New Company** The Griffin & George Group have formed Griffin & George (Research and Development) Ltd, to carry out research into and development of scientific instruments and apparatus for laboratories and process controls. The major effort will be concerned with analytical techniques.



BERKELEY BLOWER ON TEST

One of the sixteen BTH 4000 h.p. motor-driven gas circulators for Berkeley nuclear power station is being tested at the Rugby works on a closed air circuit

● **Stainless Machinists** Screw Machine Products Ltd, of Woburn Green have been approved by UKAEA as having works facilities suitable for the supply of electrical control gear, remote handling equipment, control rod and fuel element components and machining stainless steels and high tensile steels. Their inspection department is especially well equipped, including optical projectors and comparators.

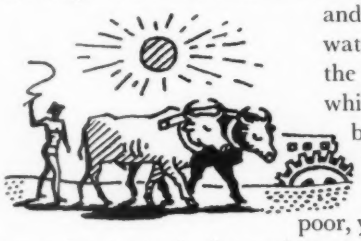
● **Overseas Tour** EMI Electronics Ltd is demonstrating its new general purpose analogue computer EMIAC II during March and April in Düsseldorf, Munich, Stockholm, Paris and Hanover. The visits to Paris and Hanover will coincide with the Hanover Trade Fair and the French Physical Society Exhibition.

● **Oil research** A large extension to the Hayes Laboratories of Wakefield-Dick now enables extended research using spectrographic analysis and radioactive isotopes to be carried out.

This is one of a series of advertisements by ***RITCHIE CALDER*** *which is appearing in the National Press to illustrate how atomic power may help man's muscle emancipation*

Muscle is the most costly power on earth

A TYPICAL SCENE in tropical countries is that of the bullock-team raising water from a well. To the chanting of the drivers, the bullocks trudge backwards and forwards, under the relentless sun, lowering the buckets into the well, hoisting the water and tipping it into the water-courses to irrigate the thirsty soil, from which both men and beasts get their food. Those peasants are poor, despairingly poor, yet they use the most expensive power in the world—muscle-power. Bullocks have to be bought, tended and fed, yet even with the meagre food and pitiful earnings of the men who drive them, the energy equivalent which they produce costs twenty times as much per unit as the energy output at Calder Hall atomic energy station.



MUSCLE POWER INEFFICIENT

A great many people in the world are poor because of necessity, they use calories in their most expensive form and energy in the most uneconomical way. Although we may glorify muscle-effort—and, indeed, laud it in the performances of athletes—it is deplorably inefficient. The advance from the steam-engine to atomic power, from the pulley-belt to automation, has represented the emancipation of man from muscle-slavery.

The paradox of power is that those who are power-deficient are power-extravagant. When we go around the house switching off lights to keep the electricity bill down, we might think of the Indian villager burning cow-dung to cook his food for his muscle-power. Because he burns that dung, instead of using it as manure, his soil is undernourished, his crops are undernourished, and he is undernourished.

This is the Misery-Go-Round of poverty; because the peasant is poor he is undernourished; because he is undernourished he under-produces; because he under-produces he is poor; and because, in 'muscle-power' countries, poverty prevails, their natural resources are underdeveloped. Such countries see in nuclear energy a break-through to industrial prosperity. The problem of how to find the money to pay for it and to train the people to handle it, is the answerable challenge of our times.

The power engineers know the answers; the mechanical engineers have created the machines. The muscle-slaves are waiting to be freed and the resources of their countries are waiting to be developed. The machine is the emancipator.

MITCHELL ENGINEERING *are designing and constructing Nuclear Power Plant to meet world needs in the New Atomic Age*

MITCHELL

MITCHELL ENGINEERING LIMITED ONE BEDFORD SQUARE LONDON

They said...

points from papers, speeches, conferences

When to refuel?

Devising the optimum practicable fuel cycle for the gas-cooled reactor will reduce fuel costs by a factor of two over the simple once-through figure. There is thus a strong incentive to do this although the practical difficulties are great. Against this background on Jan 22–23 the Institute of Physics held a symposium on nuclear fuel cycles and the AEA discuss different aspects of the problem.

Talking about operational aspects of fuel cycling N. L. Franklin from the AEA Industrial Group said it would take a very long time to achieve equilibrium in a fuel cycle. With the present aim of 3000 MWd/t it would take between four and five years before it was all burnt up and in the meantime a newer element with possibly a higher burnup performance might be developed. Thus in the 20 year life of one of the civil power stations—not forgetting that the cycle must be tapered off at the end—it could be that true equilibrium will never be reached. On the question of fuel element manufacture Franklin pointed out that it is practicable with a modern plant to make a complete fuel charge for a large gas-cooled reactor in about a year. This will last at least four years and so theoretically, as far as this particular reactor is concerned at any rate, the fuel plant stands idle for 3 years.

Speaking for the CEGB, Dr C. P. Haigh said that a large nuclear reactor shut down for one day would cost about £8000 and so they must be kept on load. This meant inevitably on-load charging. He thought that delayed onset of fuel cycling might have economic advantages but that this would be determined by the maximum speed at which the fuelling machine can work. With the present machines it would probably not be possible to delay and cycling would have to commence immediately. At first the Generating Board operatives would stick to very simple fuelling systems to gain experience.

While Calder Hall is providing valuable experience for first round stations, there will be no comparable help for the next generation, said Mr F. W. Hutber (Risley). The AGR, he said would prove the engineering of elements but it would not give any failure statistics. He added that ultimate fuel costs would be determined by the throughput of the AEA's plants.

Summing up the symposium, P. W. Mummery (Harwell) said he looked forward to a similar conference in about three years time when some real experience had been accumulated.

Industrial Saving

Organic moderated reactors promise cheaper steam for industrial processing in Europe. Whilst ninety-five per cent of Sweden's electricity is derived from water power, some seventy per cent of the total energy produced for all purposes is now based upon imported fossil fuels. Taking these figures Dr Chauncey Starr the General Manager of Atomics International Division, North American Aviation Inc, when addressing the Royal Swedish Academy of Engineering Sciences in Stockholm, advocated 'a greater use of nuclear energy in industry.'

CHAUNCEY STARR
No 'best' reactor

After reviewing various reactor concepts and stating 'at this time there is no "best" reactor for the production of the required economic electric power' Dr Starr coupled a particular type of reactor, the OMR, to the heat consumption by manufacturing industries.

'The possibility of a reactor cooled and moderated with an organic fluid has been under investigation for a number of years. Such a reactor incorporates a number of basic advantages. The organic shows negligible corrosion with ordinary construction materials, low induced radioactivity in the coolant, elmination of hazardous coolant reactions with uranium or water and low coolant vapour pressures permitting low operating pressures.' OMR designs have been considered for process steam applications and although 'the United States is not a particularly attractive market for nuclear power' 25, 50 and 75 thermal megawatts design sizes have been assessed for European applications. The cost of process steam for these three designs range from approximately $2.80 per metric ton of steam for the 25 MW reactor to as low as $1.60 per metric ton for the 75 MW reactor, compared with between $2.50 and $3.00 per metric ton for steam from conventional fuels in Europe.

'It would thus appear that Sweden is especially attractive for the application of atomic energy' and such plants would be useful in the pulp and paper industry as well as providing means of comparatively evaluating the potentials of other types of reactors at present being reviewed by the Swedish State Power Board.

Too much breeding

Heavy water is definitely too expensive at the present prices said Mr W. Kenneth Davis, vice-president of Bechtel Corporation at the First International Symposium on Nuclear Fuel Elements. After reviewing relative fuel rental and purchasing costs it is considered that 'there probably is a heavy water price, perhaps one-half of the present price or something less than that, at which its use as a moderator would appear attractive in competition with other types of reactors. However, it does not appear realistic to expect such a price reduction at the present time.' The conclusion is that while development should not be dropped it would be wise not to give 'too great an emphasis' to heavy water moderated reactors 'under the present circumstances.'

Referring to the recent announcements emphasizing the need for breeder reactors Mr Davis stated 'In fact, in some cases it has been implied that scarcely any other type of reactor merits further serious support. I believe it would be a serious mistake from the practical and realistic point of view.' As present US uranium production could support all the US electric power production were it all nuclear based 'without even resorting to plutonium recycle let alone breeding' it is felt that there is no real need for breeder reactors for the next thirty or forty years. Development should first be on the lines of economically useful power reactors and then only when 'the cost of nuclear raw materials increases relative to the other costs' improved utilization of the fuel would be a key item leading to breeders. When this stage is reached the cost would be met by the nuclear power industry in the same way that other improvements in the power industry have been brought about during the past fifty years or more.

Progress could be achieved by drastically reducing 'fuel fabrication and processing costs.'

EKCO electronics announce new fully-transistorised Thermocouple Trip Amplifier

- **Upper trip setting, normally 0-250°C, may readily be extended to 1200°C. Accuracy better than 0.4% of trip temperature over whole range—maintained over extended ranges.**
- **Alarm accuracy better than 2% of meter range.**
- **Response time less than 0.2 seconds.**
- **Indefinite life.**
- **Small in size (4″ x 8¾″ high): four units complete with power packs fit standard 19″ rack panel 8¾″ x 13″.**

The Ekco range of reactor instruments also includes the following:—

Reactor Period Meters with alternative ranges.
Reactor Power Error Meter.
Resistance Thermometer Trip Unit.
Shut-Down Amplifier (with start-up facilities and shut-down state trip).
Fast Neutron Monitor (installed).
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Effluent Monitor.
Battery Box Assemblies.
Logarithmic Gamma Health Monitor (installed).
Slow Neutron Survey Meter (portable).
Beta-gamma Survey Meters (portable).
Decade Voltage and Current Generator (general purpose test unit).
Reactor Period Meter Test Unit.

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NAMES IN THE NEWS

Mr A. R. Cooper, a full-time member of the Central Electricity Generating Board, and director of the Eastern London and South Eastern Regions of the Board is taking up special responsibilities for the operations (including nuclear) and personnel work of the Board. To help him he will have **Mr A. E. Hawkins** in his new post of chief operations engineer and **Mr S. S. Scott,** chief personnel officer.

Two leading British nuclear experts **W. Murgatroyd,** Professor of Nuclear Engineering at Queen Mary College, and **J. M. Kay,** Professor of Nuclear Power at Imperial College, leave London in March on a British Council lecture tour of Latin American countries.

Mr P. G. Smyrk has joined the board of Johnson, Matthey & Co as joint managing director.

Servomex Controls have appointed **Lt Col J. P. Flowerdew** to be production manager in charge of all production facilities.

Managing director of Lancashire Dynamo Electronic Products, **Mr R. A. Bent,** has recently been appointed to the board of the parent company Lancashire Dynamo Holdings Ltd.

Sir William Scott, managing director of Armstrong Whitworth (Metal Industries) and **Sir Richard Bellingham Graham** have been appointed directors of Head Wrightson Teesdale Ltd.

Mr S. G. Catto, managing director of Morgan Grenfell and **Mr R. N. Millar,** general manager of GEC's heavy engineering and nuclear division at Erith, have been appointed directors of the company.

English Electric's managing director **Mr H. G. Nelson** has been awarded the Royal Society of Art's Benjamin Franklin medal for 1959.

Mr D. D. Morrell has been elected a director of Mitchell Engineering Ltd. Mr Morrell is managing director of The Mitchell Construction Co.

Mr W. L. Day has joined the board of W. S. Atkins & Partners where he is project engineer of the nuclear engineering group. Mr Day was at one time assistant director of the UKAEA's Chemical Plant Design group at Risley.

The CEGB have appointed **Dr J. A. L. Bonnell** nuclear medical officer and deputy to **Mr C. A. Adams,** the board's chief nuclear health and safety officer.

On account of ill health **Mr Gordon Helps** has retired from his position as joint managing director of Humphreys & Glasgow Ltd.

Power Jets (Research and Development) have appointed **Mr N. M. Clark** to be chief engineer in succession to **Mr J. Hodge.** Mr Clark has been particularly engaged in the design of circulators for gas-cooled reactors.

Arthur V. Peterson has left AMF to form Arthur V. Peterson Associates, an atomic energy consulting firm.

Mr C. R. Jones and **Mr P. K. Richards** have become directors of John Thompson Water Tube Boilers. Mr Richards is nuclear contracts manager.

Vice-Admiral Sir John Eaton has joined Marconi's as chief of administration of their Research and Development Laboratories.

Dewrance & Co Ltd announce that Mr **Andrew Brown** has been made assistant sales manager. He is especially responsible for the sale of special valves designed for nuclear power plants.

E. McALPINE

W. L. DAY

A. R. COOPER

R. A. BENT

Mr H. West has become assistant managing director of Metropolitan-Vickers. He ceases to become director of electrical engineering.

Mr R. Edwin McAlpine has been elected chairman of the Nuclear Power Plant Co Ltd in succession to the late **Sir Claude Gibb.**

OBITUARY

NUCLEAR POWER regret to record the death of **Dr Hans Sulzer,** president of Sulzer Brothers Ltd at the age of 82.

MARCH DIARY

ICE Institution of Civil Engineers, IMechE Institution of Mechanical Engineers, IEE Institution of Electrical Engineers, IChemE Institution of Chemical Engineers, IP Institute of Physics, PS Physical Society, SCI Society of Chemical Industry, IM Institute of Metals, IMet Institution of Metallurgists, IMM Institution of Mining and Metallurgy, IPE Incorporated Plant Engineers, SIT Society of Instrument Technology, BritIRE British Institution of Radio Engineers, RSH Royal Society of Health, IR Institute of Refrigeration.

THURSDAY 5

LONDON SIT Symposium on the use of data recorded on industrial plant *G. Nonhebel, F. G. Webster* 6.00 Manson House, Portland Place

MANCHESTER BritIRE Closed-circuit television equipment *R. E. Blythe* 6.30 Reynolds Hall, College of Technology, Sackville St

FRIDAY 6

LONDON IMechE Approximate equations for the properties of superheated steam *Prof J. H. Horlock* 6.00 at the Institution

BIRMINGHAM IMarE Energy from the atom *Prof C. F. Powell* 7.00 Birmingham and Midland Institute, Paradise St

THURSDAY 12

LONDON Plastics Institute 10th annual lecture International competition in the chemical industry *S. P. Chambers* 6.30 Wellcome Foundation Building Admission by ticket

WEDNESDAY 18

NEWCASTLE SIT Operating experiences on automatic control of large steam generators *J. S. Holt* 7.00 King's College, Stephenson Buildings

HALIFAX IPE The production of power from nuclear energy *A. L. Shaw* 7.30 Percival Whitley College of Further Education

THURSDAY 19

MANCHESTER IMechE Special design and construction features of the Bradwell Nuclear power station *G. H. Inglis* 6.45 Engineers' Club, Albert Sq

GLASGOW BritIRE Application of magnetic amplifiers to electrical switching *J. A. Purdie* 7.00 Institution of Engineers and Shipbuilders, 39 Elmbank Crescent

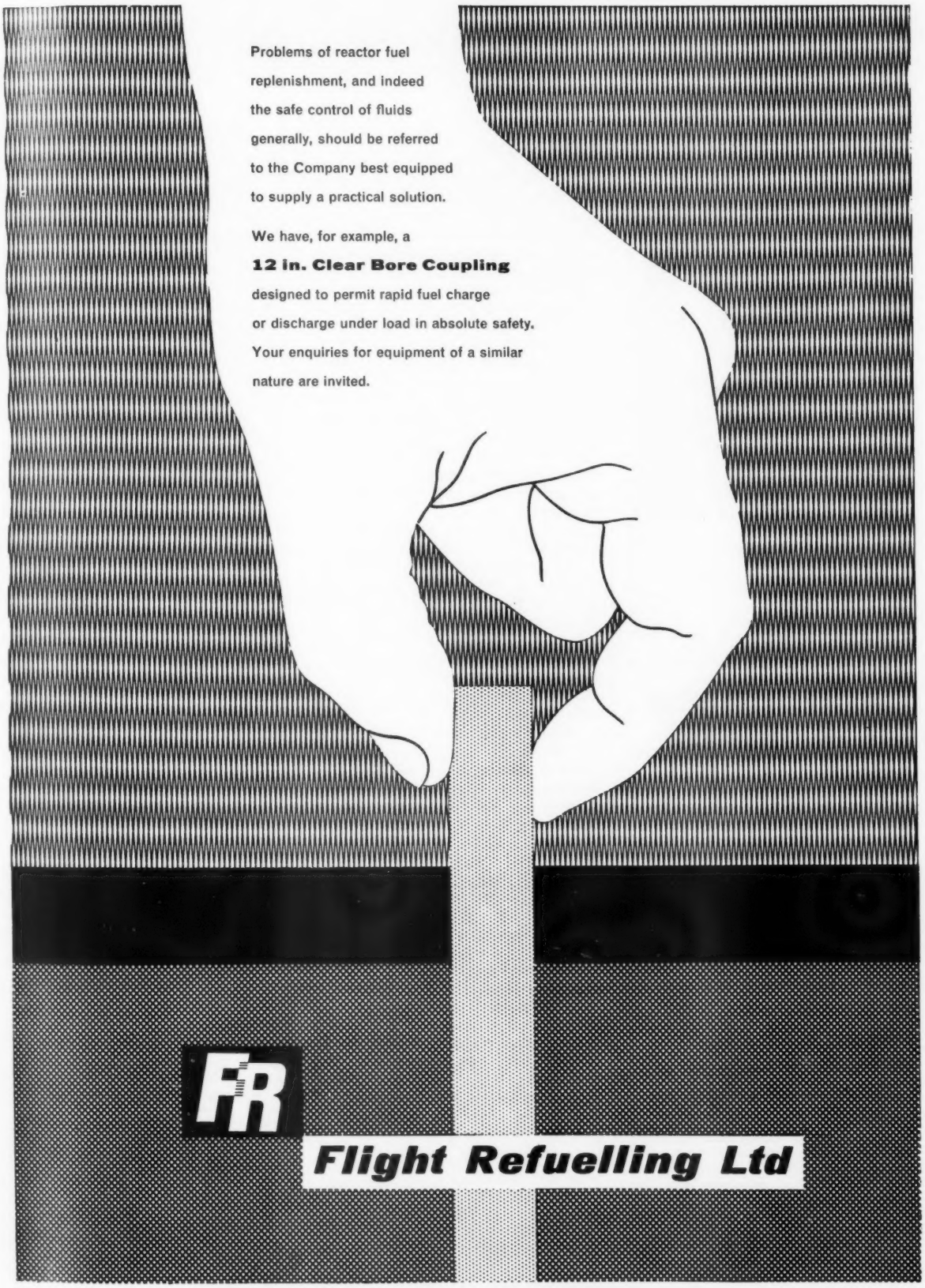
FRIDAY 20

EDINBURGH BritIRE Application of magnetic amplifiers to electrical switching *J. A. Purdie,* 7.00 Department of Natural Philosophy, University, Drummond St

TUESDAY 24

LONDON SIT New direction in engineering psychology *Dr R. Conrad* 6.00 Manson House, Portland Place

BRISTOL BritIRE Recent advances in travelling wave tubes *P. F. C. Burke* 7.00 School of Management Studies, Unity St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to supply a practical solution.
We have, for example, a
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designed to permit rapid fuel charge
or discharge under load in absolute safety.
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Book Reviews

Early stages

Nuclear Rocket Propulsion by R. W. Bussard and R. D. DeLauer London 1958: McGraw-Hill Series in Missile and Space Technology 370 pp Price 77s 6d

The ultimate inadequacy of chemical reactions as a source of energy for the propulsion of vehicles through space has long been recognized. A considerable incentive exists, therefore, to apply nuclear energy in rocket propulsion and in recent years a considerable amount of serious scientific speculation has been devoted to the problem of developing a nuclear rocket. This has lately been taken a stage further in the USA where a definite development programme known as the Rover Project has been initiated. The authors are both engaged on this project and are well qualified to write about the subject.

The work is divided into nine chapters, of which the first is merely a brief introduction. In dealing with the fundamental dynamics of rocket flight in space, and the possible application of a nuclear reactor to heat a working fluid in a rocket thrust chamber, the relevant physical and chemical properties and performance characteristics of likely working fluids are described, but the temperature range over which most of the relevant properties are described is restricted to 7000°R (3900°K.).

The section on system analysis tends to become tangled up in a mass of elementary but tedious mathematical expressions and so many parameters are introduced, without an adequate notation list, that it is almost impossible to sort out the physical implications of the results which are presented in the various graphs. The main failing of this chapter is that it appears too early in the book and the authors do not discuss their basic assumptions in any detail. Many of these are matters of conjecture which should have been considered at greater length.

The ensuing chapters on 'Heat transfer and fluid flow,' 'Materials' and 'Nucleonics' should have been treated as forming a basis for the assumptions made in the system analysis and, therefore, they should have preceded that section. Unfortunately, the authors have tended to divorce these subjects from the rocket propulsion theme and deal with them in a rather general manner. This is particularly true of the nucleonics section which contains scarcely any reference to the specific problems of a possible nuclear rocket reactor, while the heat transfer section contains only one partly worked example relating specifically to such a reactor.

A vital aspect of reactor development is that of testing the various components and the reactor as a whole under actual operating conditions or conditions closely resembling those which obtain during operation. This will be particularly difficult in the case of a rocket reactor because of the high temperatures and the enormous power densities which are involved. The authors describe some of the test facilities that are in use at Los Alamos and discuss a few of the problems that might be encountered in testing rocket reactors. The treatment is, unfortunately, rather superficial and no really useful details are given.

The authors have undertaken an extremely difficult task. The development of nuclear rocket propulsion is in a very early stage and still involves a great deal of speculation. One of the shortcomings of the book is that insufficient emphasis is laid upon the conjectural nature of the subject and one gains the impression from it that the principles are all very well established and that nuclear rocket engines are in the same highly developed stage as, say, submarine reactors. Until rocket reactors have been in frequent operational use it will not be possible to write a textbook, in the normally accepted meaning of the word, on this subject. In the circumstances the authors would have done better to have discussed all the principles and problems in the broadest sense and not to have confined themselves too rigidly to the conditions that appear to them to be realizable in the immediate future. Nevertheless it is an interesting book and contains a considerable amount of valuable data. The lists of references are particularly comprehensive.

L. R. Shepherd

Time savers

Handbook of Physics Edited by E. V. Condon and Hugh Odishaw 1504 pp London 1958: McGraw-Hill Price £9 14s
Nuclear Engineering Handbook Edited by Harold Etherington 1872 pp London 1958: McGraw-Hill Price £9 14s
Kempe's Engineers Year Book 1959 64th edition Edited by C. E. Prockter 2 volumes 1324 pp and 1416 pp London 1959: Morgan Bros Ltd. Price £4 2 6

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can ever completely replace the specific textbook, they undoubtedly provide a convenient guide through the maze of widely scattered literature and give useful starting points for new studies.

The *Handbook of Physics* is a monumental work compiled by 88 specialist authors, many of whom are well known. The contents are divided into 9 parts each of which contains several chapters. Titles of the parts are: Mathematics, Mechanics of particles and rigid bodies, Mechanics of deformable bodies, Electricity and magnetism, Heat and thermodynamics, Optics, Atomic physics, the Solid state, Nuclear physics. Each chapter concludes with a selective bibliography, that at the end of the chapter on nuclear structure by L. Eisenbud and E. P. Wigner being noteworthy for its extended treatment. Throughout, the approach is by way of principles rather than applications, with theory rather than experiment. An excellent index enables one to navigate this great work quite easily.

The same publishers' *Nuclear Engineering Handbook* is also a first edition and consists of 14 sections compiled by 70 authors. Conceived on somewhat similar lines to the *Handbook of Physics*, it is however considerably more practical in approach and illustrates its points by frequent reference to actual reactors. Not of course that reactors are the only subject covered. Some section headings are: Nuclear physics, Reactor physics, Radiation and radiological protection, Control of reactors, Fluid and heat flow, Reactor materials, Chemistry and chemical engineering, Nuclear power selection, Mechanical design and operation of reactors, Isotopes. The chapter on gas-cooled reactors is rather fragmentary and one would have thought that a British or French author might have been better qualified to write it. On liquid-cooled reactors it is, of course, first rate and it is difficult to fault the physics, metallurgy or chemistry. Throughout the references are copious, albeit heavily biased towards the American literature. In time, the Handbook seems to stop short of the 1958 Geneva Conference and clearly a second edition will somehow have to include new material made available there—in particular a section on thermonuclear fusion will be needed.

The well-known British handbook, Kempe's, is now in its 64th year with three sections completely rewritten—Flow metering and mechanical testing, Refrigeration, Paints and varnishes. In addition, minor revisions have taken place in several other sections. The short chapter on atomic power is however still totally inadequate and needs completely rewriting. It is the policy of the publishers to carry out a certain amount of complete revision each year and it is to

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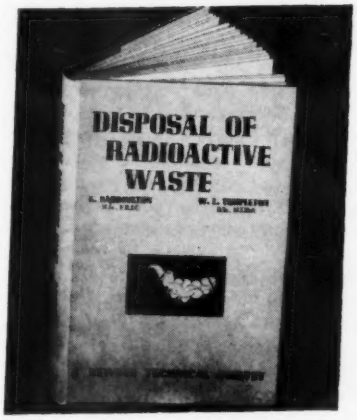

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The authors both hold appointments at the Windscale plant of the U.K.A.E.A.

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be hoped that nuclear energy will receive attention in the next edition.

C. D.

Clear introduction

Nuclear Reactor Metallurgy Walter D. Williamson and William F. Murphy D. van Nostrand Company Inc Price 42s

The declared aim of this book is 'to give every engineer and scientist a clear introduction to nuclear metallurgy'. Within these limitations it succeeds, and it appears to this reviewer that an engineer, having waded through its 358 pages, should be able to ask him the right questions and to understand a reply phrased in fairly technical language.

The book originates in the course of lectures on reactor metallurgy provided at the Argonne National Laboratory. It starts with a thorough treatise on preparation and properties of uranium metal, dealing in detail with laboratory techniques and physical metallurgy. Irradiation phenomena are dismissed rather cursorily and followed by a discussion of the special problems presented by plutonium, thorium, beryllium and zirconium. After a short treatise on liquid metals and ceramics, the book ends with an excellent survey of nondestructive testing techniques.

There are however many grounds for criticism. A book with this title should be much more directly concerned with the phenomena limiting the conditions of operation of materials in reactors, and should highlight such matters as fissionable material/can/coolant compatibility and change in the impact properties of pressure vessel steels. It is such problems as these, coupled with the behaviour of fission products, that are the chief concern of the reactor metallurgist now. The problems associated with the anisotropy of uranium have mostly been solved by heat treatment, an important subject that is only mentioned in passing. Moreover, the book completely ignores magnesium as a canning material in spite of its technological and economic importance.

The timing of the book in this country is also unfortunate. It is based largely on the First Geneva Conference and, after the second, is woefully out-of-date, containing no reference to swelling of uranium or fission product evolution for UO_2. It can be recommended within its limitations of scope and timing. It contains much useful information and its references and bibliography are extensive and drawn from both sides of the Atlantic.

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Rapid training

Basic Electricity Five volumes London: The Technical Press Ltd Price 55s

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Semiconductors Number 4 of Texas Instruments' Semiconductor Application Reports deals with d.c. power supply circuits using silicon rectifiers. Copies of this 35-page technical book are available free to enquirers.

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OMR Atomics International have brought out an illustrated booklet on their organic moderated reactor which they can now offer at a firm price with guaranteed plant performance.

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Synthetic crystals Publication from Hilger & Watts describes their range of crystals including mounted crystals and crystals for infra-red spectroscopy. The firm also have available a folder with leaflets on digitizers of various kinds.

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Ferranti computer Pegasus 2, a new version of the original Ferranti Pegasus digital computer is subject of list DC 38 published at the end of last year.

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Heat exchanger Some typical uses of the APV Paraflow plate type heat exchanger, first introduced in 1923, are described in new leaflet.

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Medicine Booklet with cover illustration of Michelangelo painting describes the medical applications of isotopes, together wth appropriate equipment such as scalers, ratemeters manufactured by Ekco Electronics.

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Handy calculator The Magnetic Valve Co have issued an extremely useful calculator for the estimating of pipe sizes for both steam and hot water. Reverse side has temperature conversion table and properties of saturated steam.

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Radioisotopes Nuclear Chicago's technical bulletin no 2 describes the evaluation of mixing techniques with radioactive isotopes. Common methods of evaluating mixing are listed.

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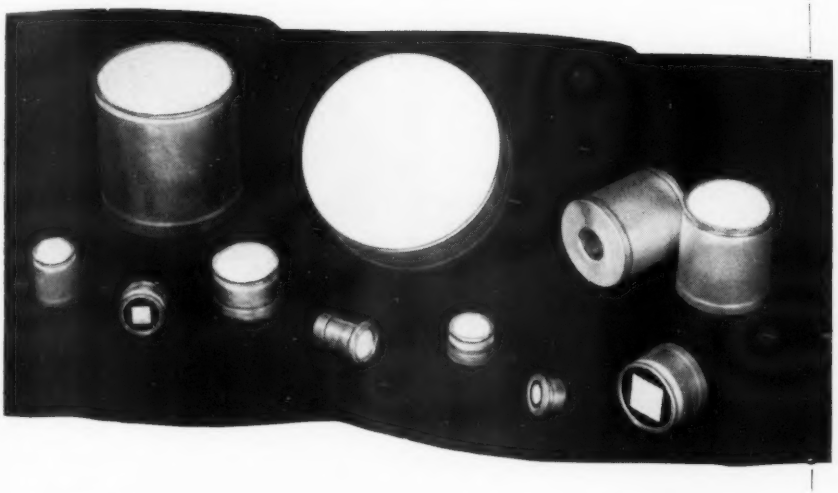

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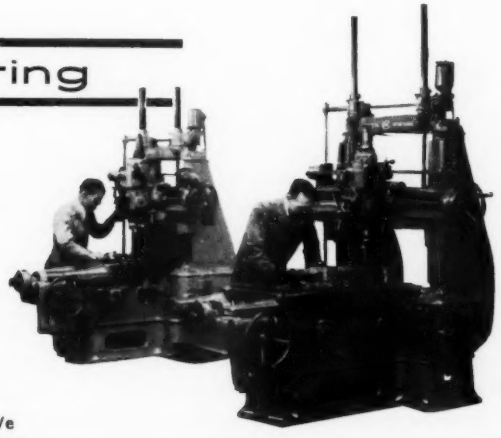

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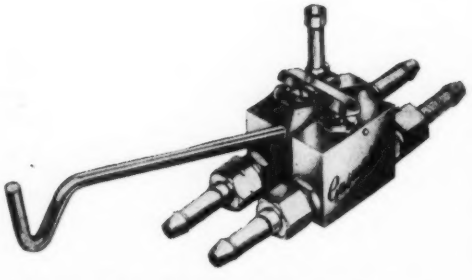

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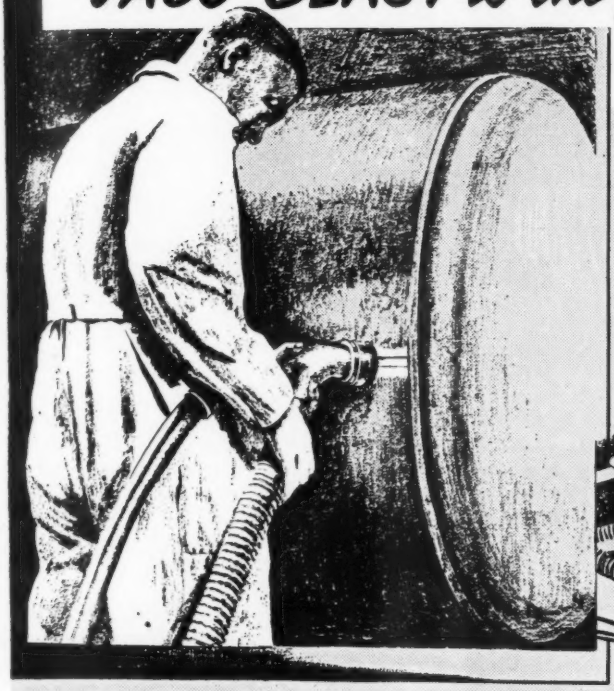

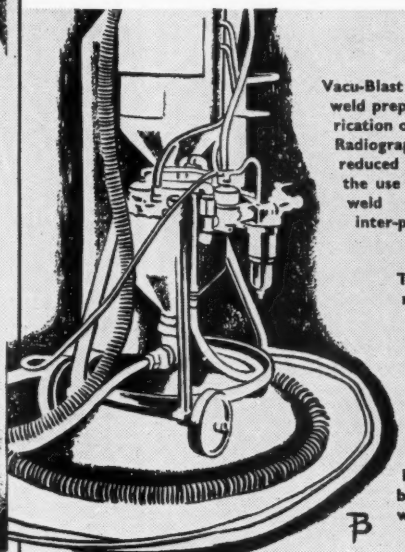

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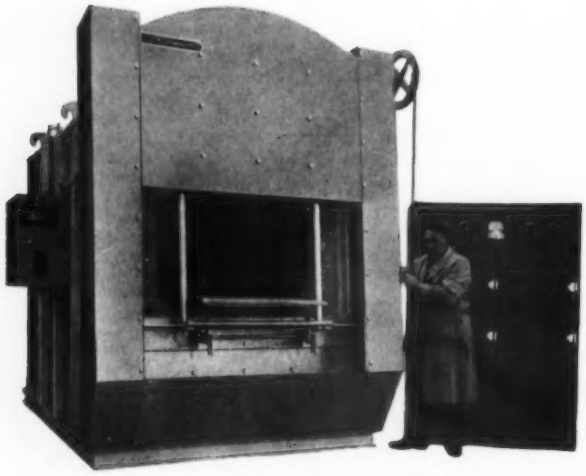

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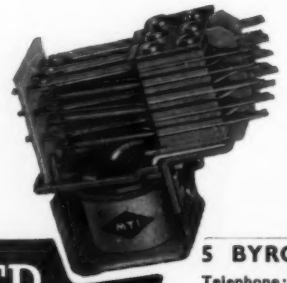

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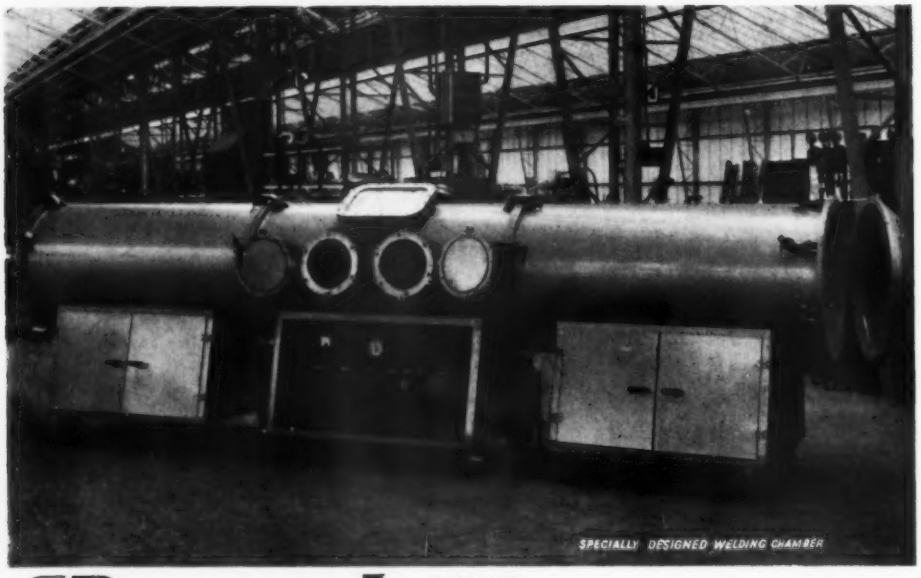

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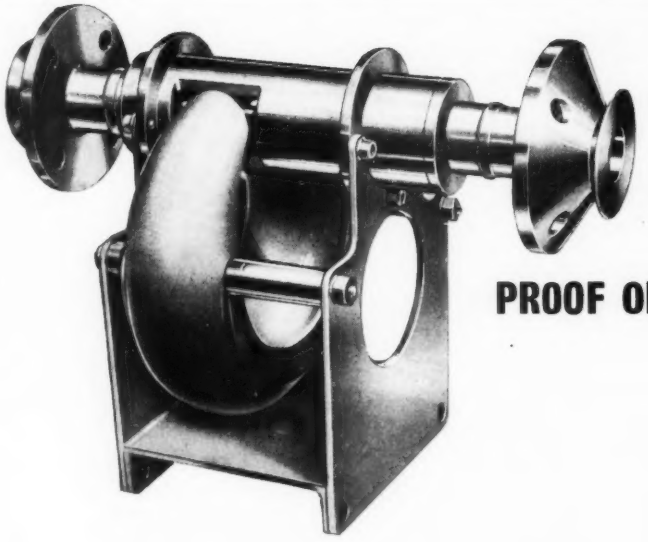

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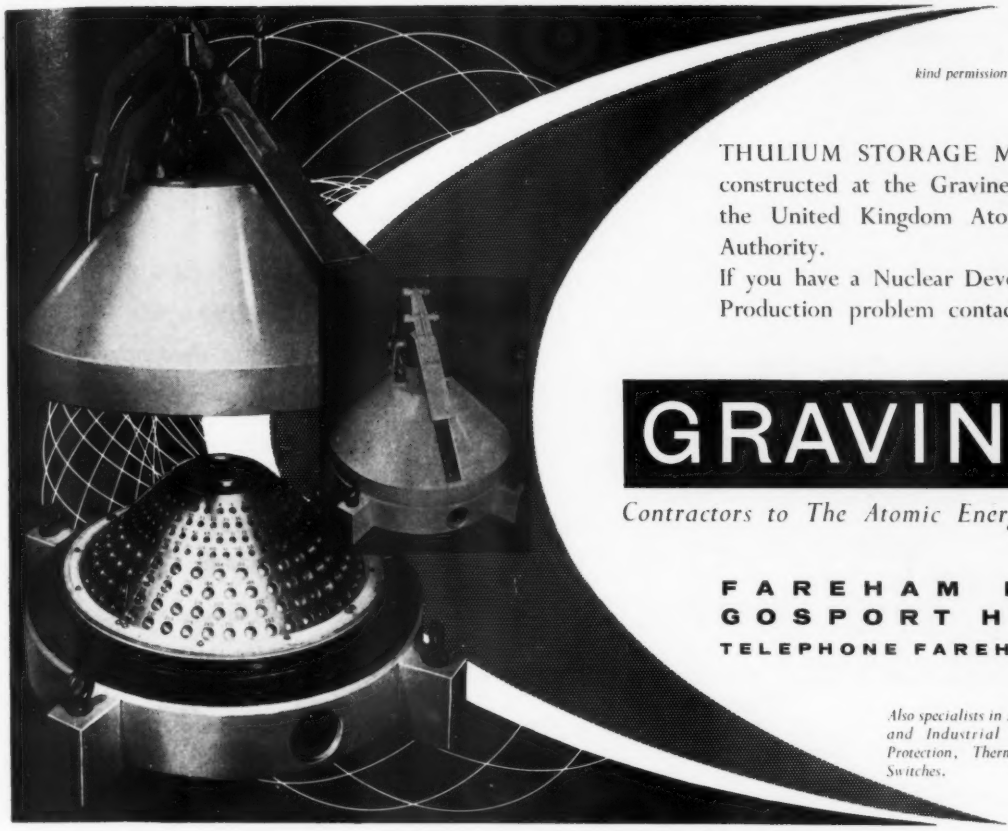

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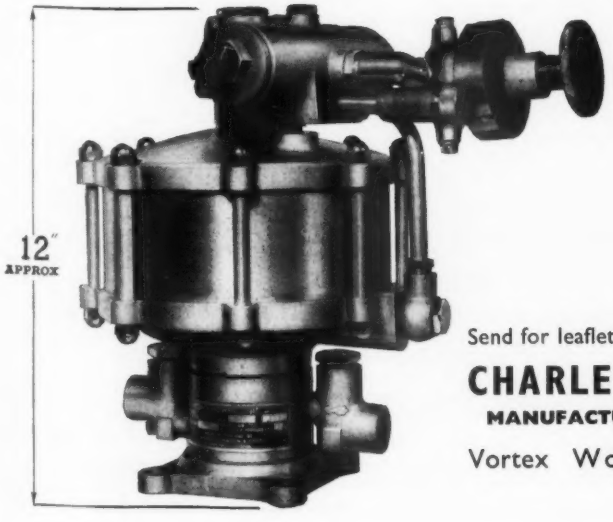

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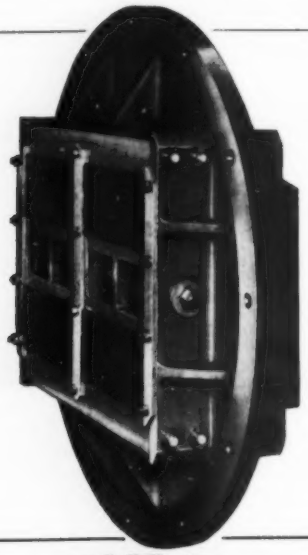

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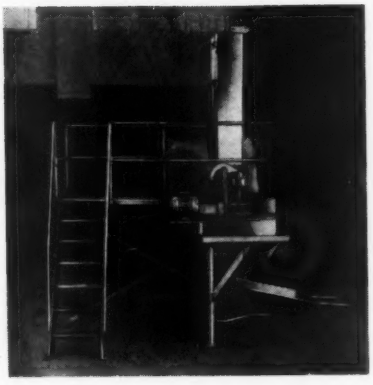

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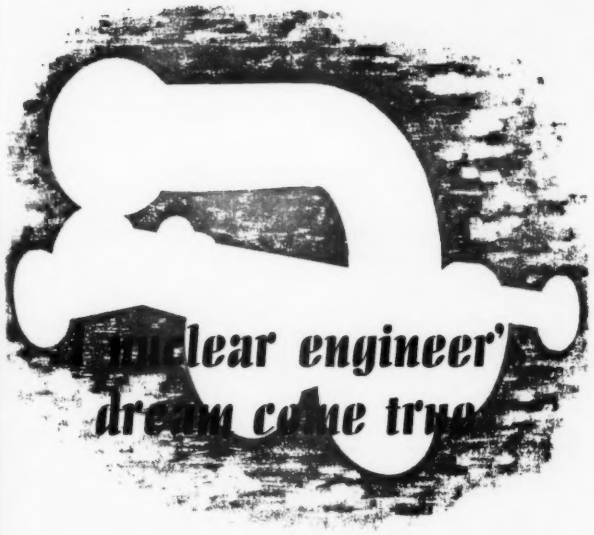

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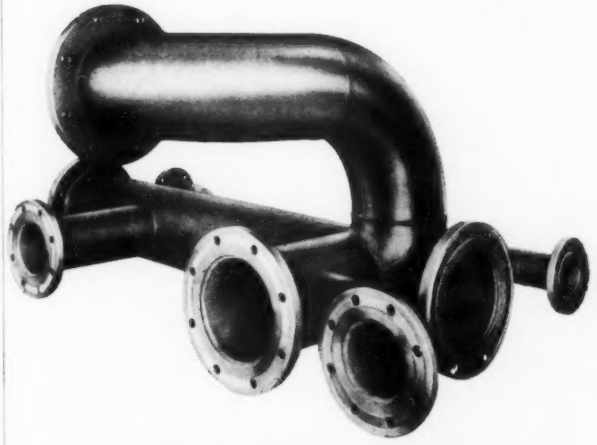

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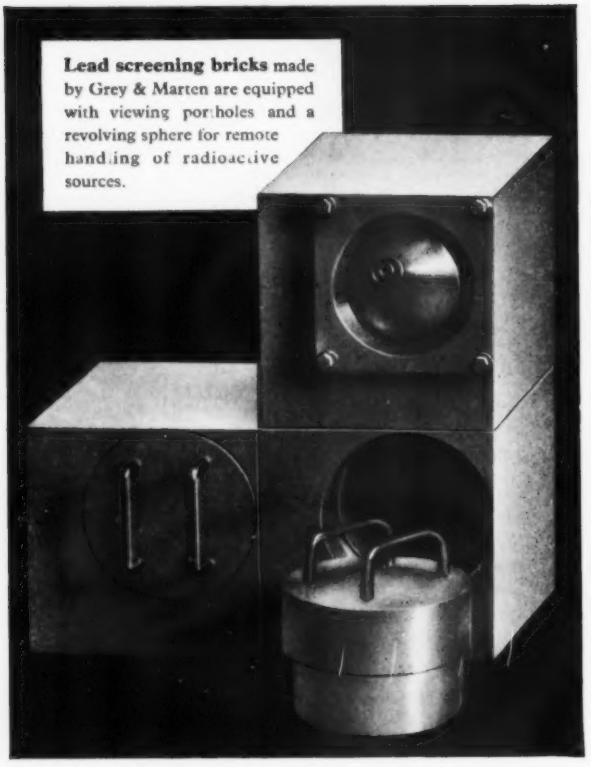

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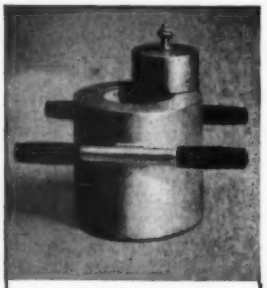

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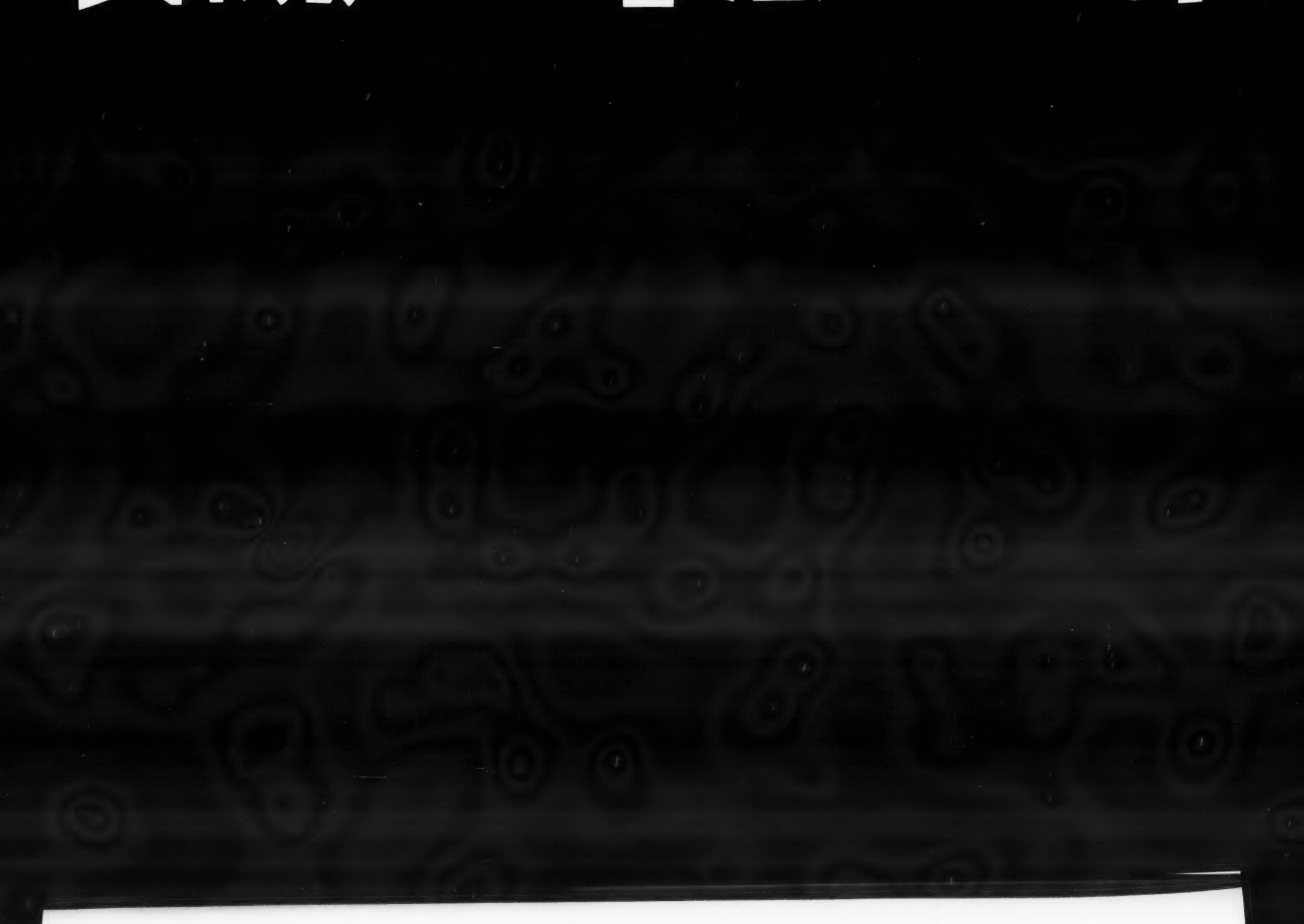

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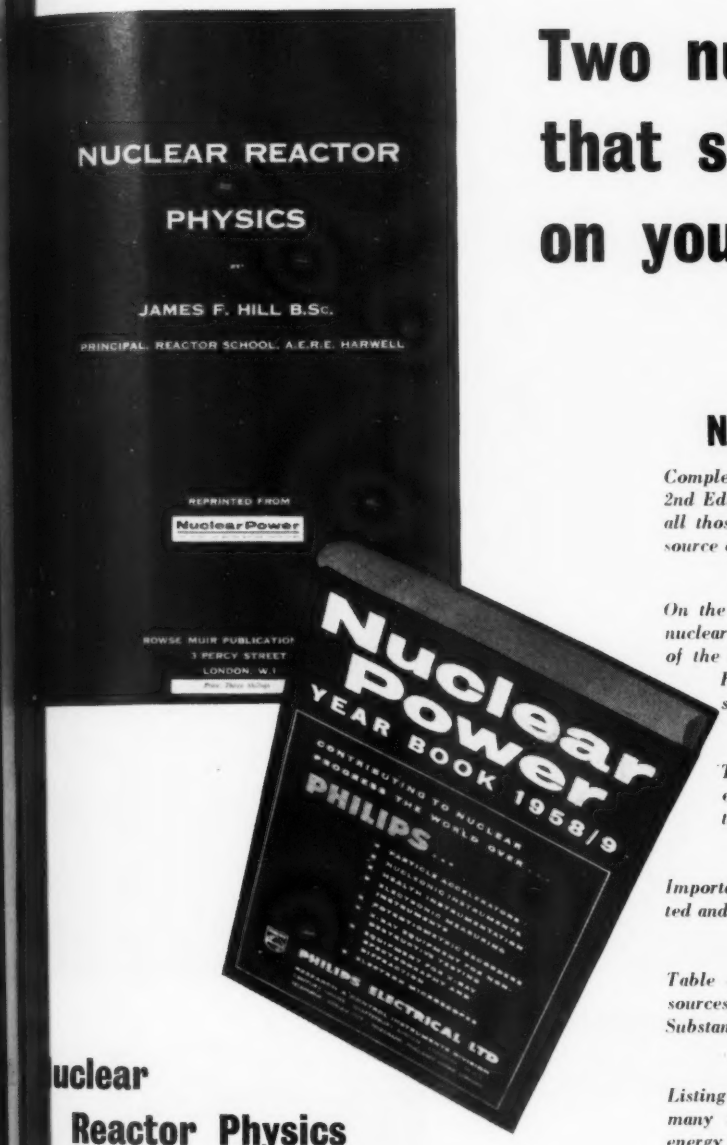

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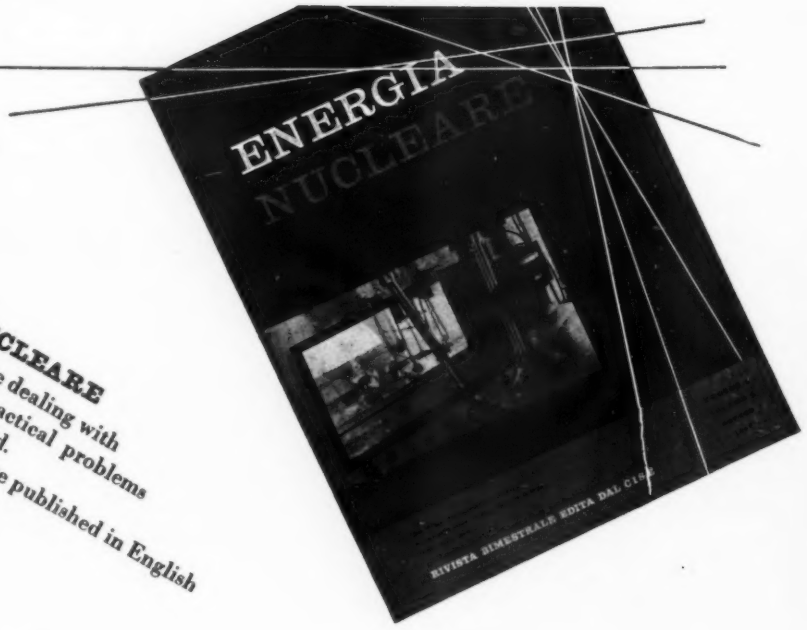

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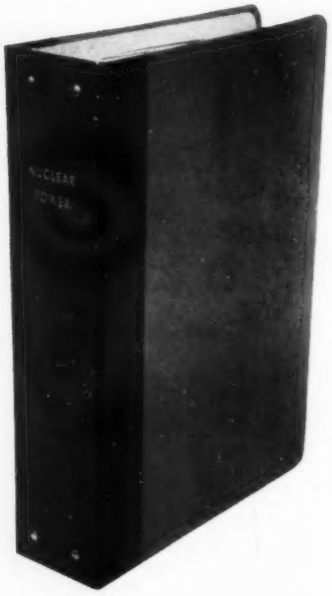

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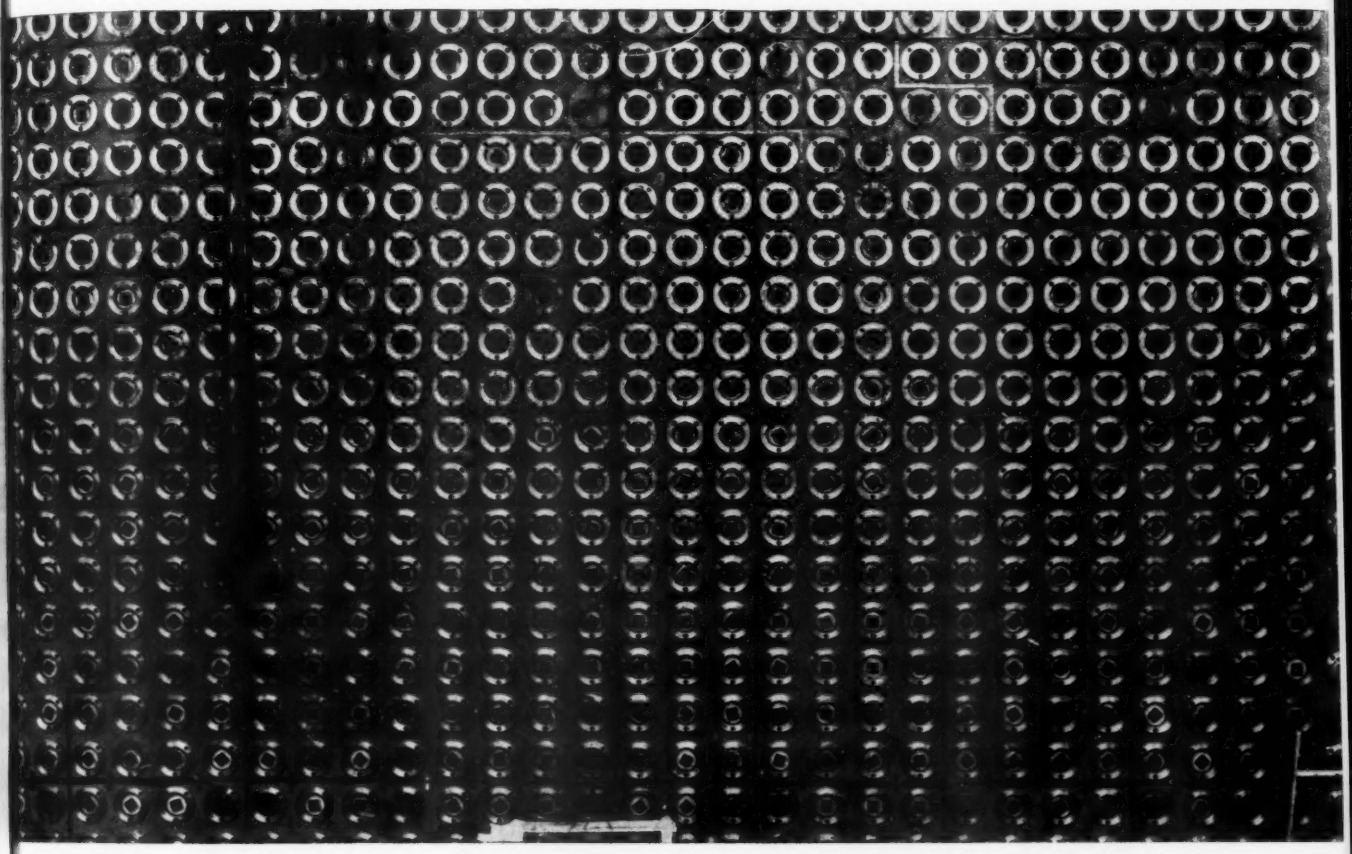

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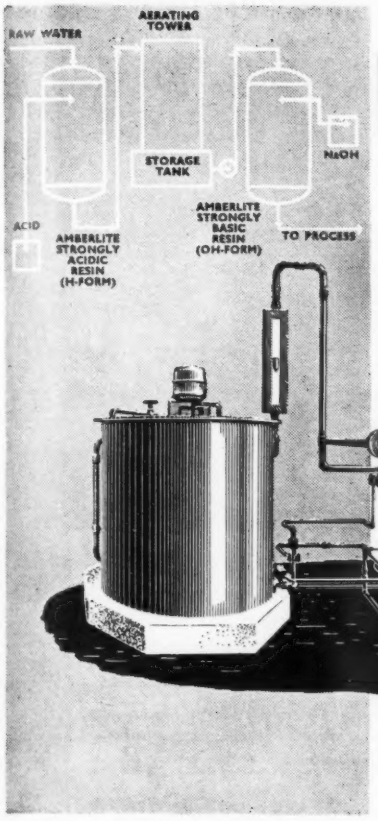

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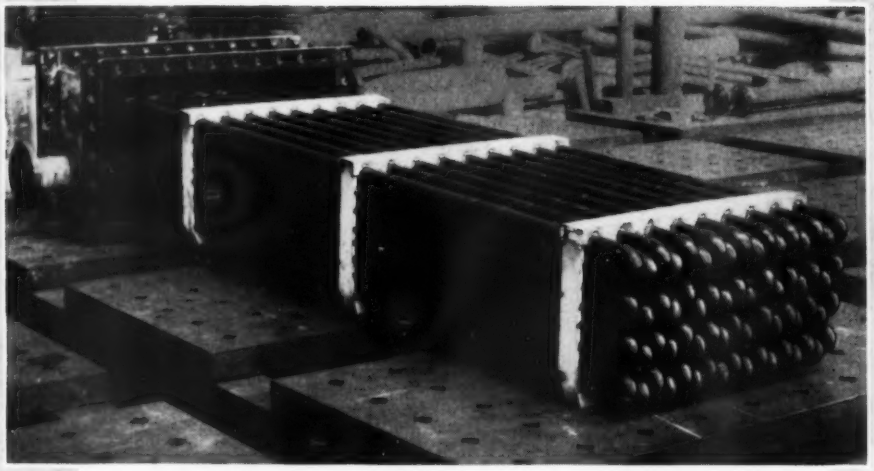

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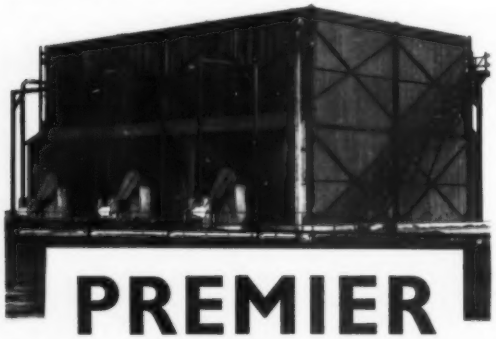

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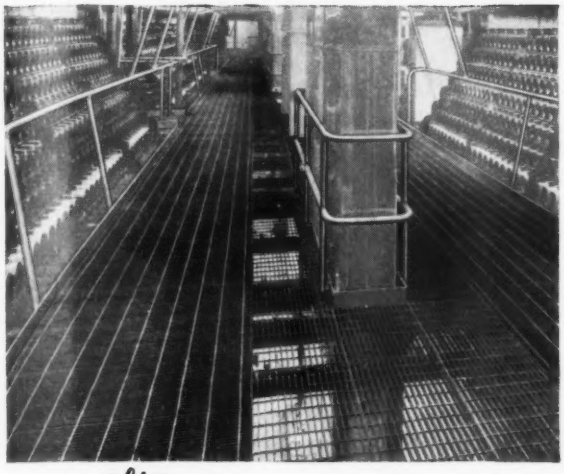

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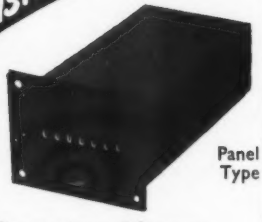

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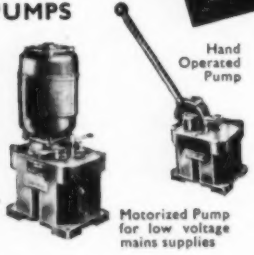

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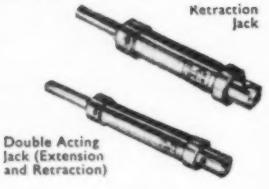

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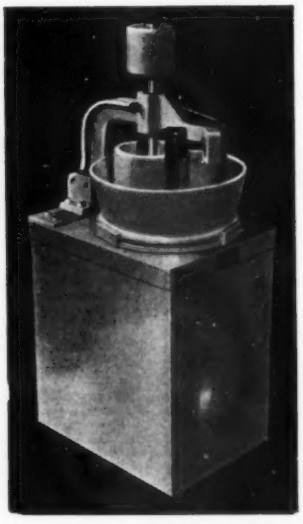

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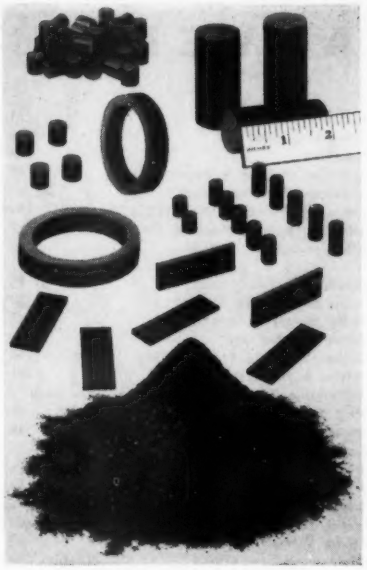

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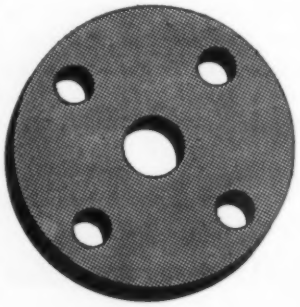

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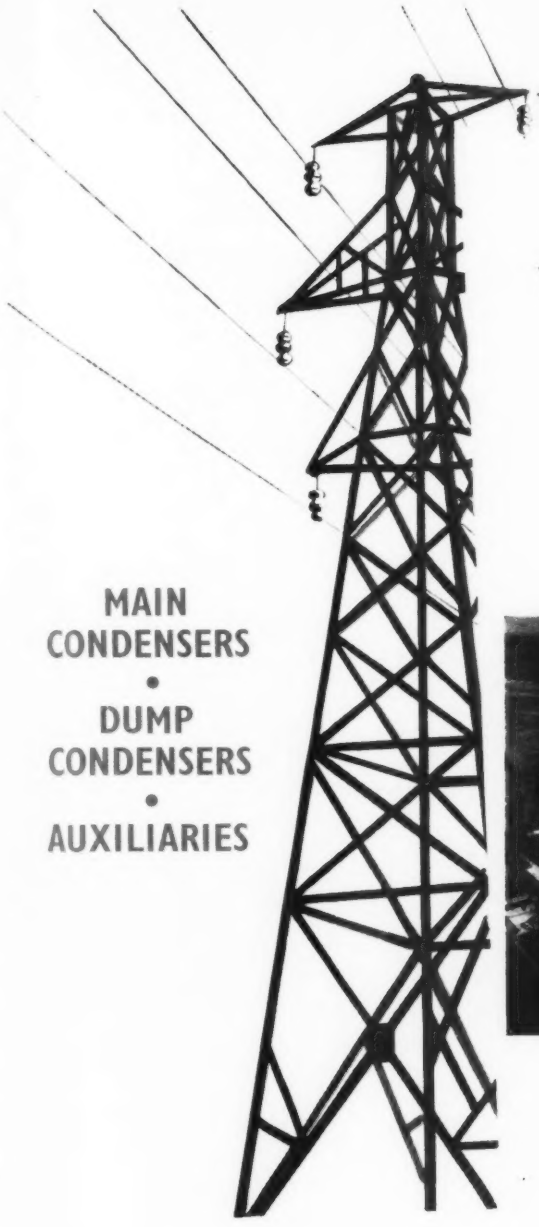

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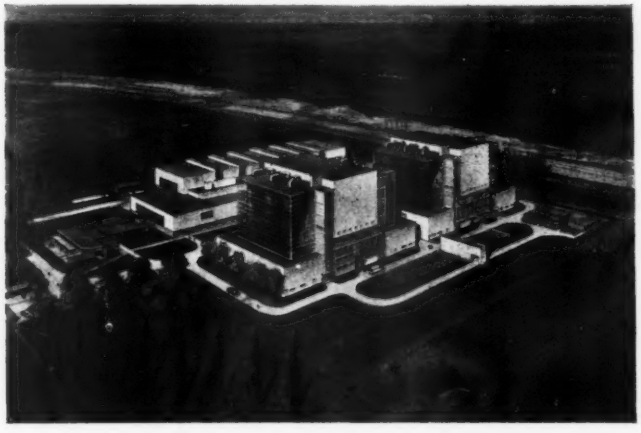

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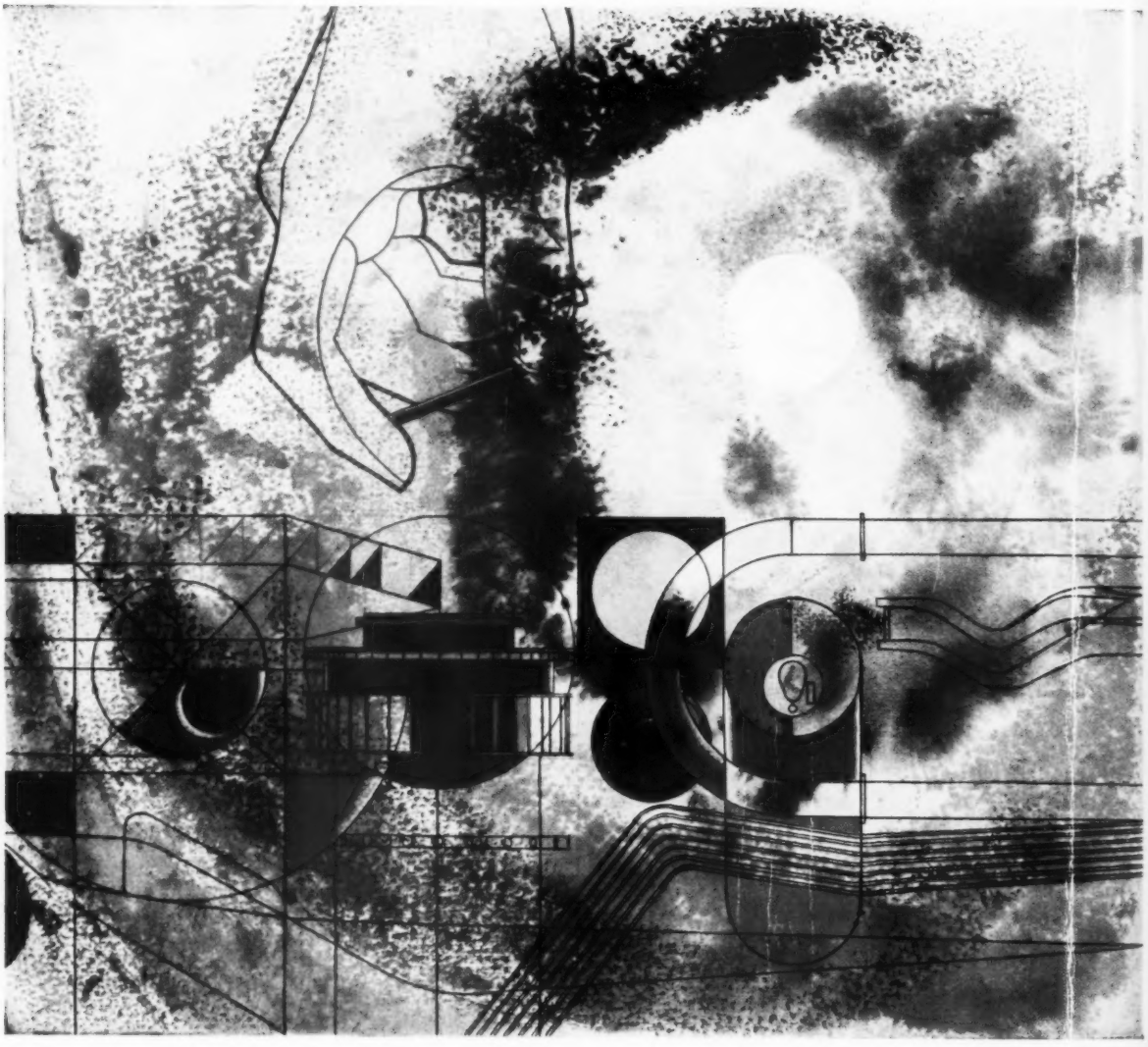

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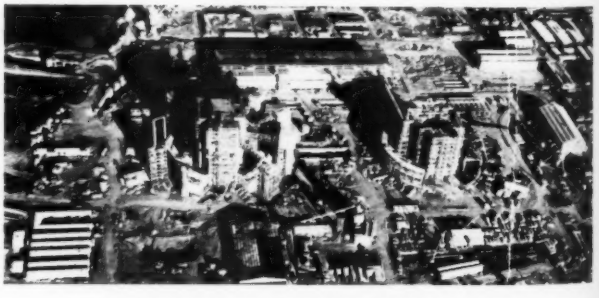

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